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Micrometeorological Field Measurements in Support of
the First ISLSCP Field Experiment
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During this study FIFE site 30 was instrumented for surface micrometeorological observations during IFC 2, 3 and 4 of the 1987 FIFE project as a part of the NASA grant "Evaporation Estimates Using Remotely Sensed Data at Different Length Scales" by R. J. Gurney, P. J. Camillo, B. J. Choudhury, and R. T. Field. Instrumentation, site description and processing of the observations have been presented in previous progress reports. The observations obtained at site 30 have been submitted to NASA Goddard Space Flight Center for inclusion in the Fife Information System data base.

A problem with the net radiation observations made by the FIFE surface flux group became evident. Co-located sites 30 and 32 employed net radiometers of two different manufactures. Even though both instruments viewed the same surface, they differed by 10 to 15% during the daytime and even more at night. Such differences were later noted between net radiation instruments manufactured by different firms at other sites. Considerable effort has been expended by the University of Delaware and University of Washington groups to understand this problem and to attempt a method of adjusting observations to a common basis. Attached here is a draft of the paper, prepared for the joint FIFE publication effort, describing the problem and methods of adjusting the observations.

The grant proposal "Evaporation Estimates..." included modeling of the field observations using the program SOILSIM. Death of the program's author, P. Camillo, interrupted this effort. R. T. Field undertook to continue this effort and ported the model to run in the UNIX environment on a Sun Microsystems 386i workstation. Documentation for SOILSIM was found to be seriously out of date and had to be revised from the program code. The original documentation was published as AgRISTARS report TM 82121 in 1982. The revised documentation is attached as part of this report.

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Calibration and Comparison of Net Radiation Instruments Used During FIFE

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Net radiation was observed at all Surface Flux, AMS, and PAM sites during the FIFE Intensive Field Campaigns (IFC's) mounted in the years 1987, 1988, and 1989 in the vicinity of the Konza Prairie, near Manhattan, Kansas. In 1987 21 Surface Flux Sites were operated by eight groups of investigators. In the subsequent years fewer sites were instrumented. Seven different designs of instruments, fabricated by five different manufacturers, were used. The identification of net radiation instruments by site is given in table 1. We undertook several efforts to establish the comparability of the observations made with these instruments. Examples of each type of net radiometer were calibrated by the sun/shade technique and subsequently compared during 36 hours by KSU personnel. Several of us (Smith, Verma, and Field) performed side by side comparisons of two or more instruments while obtaining flux observations during 1987. Subsequently, in 1989 and 1990, Fritschen performed additional sun/shade calibrations and comparisons on examples of these instruments. During the summer IFC's in 1987, a mobile set of instruments (Nie et al. ...) was deployed for several days at each of a number of sites to obtain comparisons with respect to a single reference instrument. It gradually became clear from the 1987 observations that even after applying the most recent sun/shade calibration values, that significant site to site variation in observed net radiation was attributable to instrument differences. This note paper will discuss these calibrations and comparisons and describe our approach to defining and reducing the site to site variation in net radiation that is attributable to instrument differences.

The net radiometers used are derivative of those described by Funk (1959, 1961) and Fritschen (1963, 1965). All consist of a thermopile imbedded in a black painted wafer 50 to 70 mm in diameter and 3 to 5 mm thick, which develops a temperature difference across upper and lower surface in proportion to the difference in absorbed longwave and shortwave radiation on the two surfaces. Hemispheric windows of polyethylene protect upper and lower sensing surfaces from convection. Differences in thermopile, wafer, and window design and construction lead to differences in instrument performance characteristics. Temperature differences across the transducer for a given radiation load vary with wafer and thermopile design. The temperature difference across the transducer should be kept small to minimize the difference in thermal losses between upper and lower surfaces. The transducer temperature should not become so hot as to generate rapid convection within the windows. Differences in window thickness

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cause differences in radiation absorption and emission. The Swissteco and Thornthwaite Miniature Net Radiometer (TMNR) have windows about 0.05 mm thick which require a small internal positive pressure to retain their hemispheric shape. The thickness is kept thin to minimize radiation absorption. The instruments from Radiation Energy Budget Systems (REBS) use a somewhat thicker window (about .15 mm) and are self supporting. Several REBS models were used, most differing only in the window arrangement. REBS models Q*3, Q*5, and the new Q*6, like the Swissteco and TMNR devices, have a single dome over each wafer surface. Model Q*4, on the other hand, had an additional thin dome about 15 mm diameter introduced within the upper and lower window in order to reduce internal convective air currents. Such internal convection appears to lead to some non-linearity in response (Field, in preparation). This "double dome" instrument was used at 13 FIFE sites during 1987. The Florida State University group (sites 2 and 38) observed the four components of net radiation with sets of upward looking and downward looking Eppley PSP pyranometers and Eppley pyrgeometers. The prygeometers were calibrated dynamically with a large mass copper heat source/heat sink apparatus at Colorado State University. The instrument output is corrected for the thermal radiation introduced by the instrument dome (Albrecht and Cox, 1977).

Nine net radiometers and four pyrheliometers were calibrated on 23, 29 and 30 July 1987 by KSU at the Evapotranspiration Research Field Site (39°06'N, 96°35'W) 10 km south of Manhattan, KS. The instruments consisted of three net radiometers fabricated by Swissteco, one by C.W. Thornthwaite Associates, one by Didcot Instruments, and four by Radiation Energy Budget Systems (REBS) or under that firm's name prior to 1987, Micromet Systems. Of these last four, two were model Q*4, of double dome window design, and two model Q*3 which are like model Q*4 except provided with a single dome window. Performance of the Didcot instrument is not examined here. Of the four pyrheliometers, three were Eppley Laboratory model PSP and one Eppley Laboratory model 8-48.

The direct beam solar radiation was measured by a transfer standard obtained from SERI, (pyheliometer TMI, model No. MKVI, SN68017; control unit model No. MKI SN18026, Tech Measurements, Inc., P.O. Box 838, La Canada, CA 91911). A clear sky period (1000hr-1400hr) was used for the calibration. The radiometers were alternately shaded and unshaded over periods of 10 to 15 minutes. Radiometer outputs were observed once per minute to determine final stable values. Solar elevations were calculated knowing the time, longitude and latitude. About 20 independent observations were made, and the highest and lowest values were discarded from the analysis. The resulting calibration factors were used by in the FIFE observations.

The new calibration factors for the REBS and Micromet instruments, one of the Swissteco net radiometer, and all three Eppley Laboratory PSP pyranometers were within 3% of the factory supplied calibration factors. For the Thornthwaite instrument, one Swissteco, and the Eppley model 8-48 the new calibration factor was within 5% of the factory supplied value. For the remaining Swissteco, the new calibration factor was 9% smaller than the factory supplied value.

After the calibration, the radiometers were left operating over a clipped fescue grass surface for the next 24 hours. Data were collected every five minutes. Signals from the instruments were not filtered to account for the rather infrequent sampling. When the radiation was varying quickly, such as caused by passing clouds, large differences occurred between instruments because of differing speeds of response. The observations were separated for analysis into positive (daytime when net shortwave radiation exceeds net longwave radiation) and night time (when net shortwave is less then net longwave radiation). The University of Nebraska Q*4 net radiometer (REBS No 87050) was arbitrarily chosen as a standard for the comparison; at the time of the comparison there was no documented analysis or absolute calibration available to suggest the design of the Q*4 instrument to be superior or inferior in performance to the other designs tested. Differences of output between the comparison standard and each of the other net radiometers was plotted against time. The differences in output between the calibrated instruments varied between 0 and about 80 W m^{-2} depending on time of day and instruments being compared. Day time differences showed considerable scatter. Approximate mean values for these differences for day times and night times, obtained by graphical inspection, are shown in table 2.

Side by side comparison among instruments were obtained at site 2 during the three days 30 June-2 July 1987. REBS Q*4 No. 87050 and Swissteco No. 6993 were run simultaneously at site 16 during most observational days. Site 32, equipped with REBS Q*4 No. 87030, was co-located with site 30, equipped with TMNR No. 511. All these observations are one half hour averages. The data from the three sites reveal similar differences in performance between pairs of instruments. The largest differences are between REBS Q*4 and the Swissteco and Thornthwaite "thin window" instruments. For example, for the clear days 20-21 August and 6-8 October at site 16 (figures 1 and 2) the REBS Q*4 instruments indicated 50 to 100 W m^{-2} larger (more positive) net radiation during daytime and 20 to 30 W m^{-2} larger at night. They also showed less response to the change in net longwave radiation at night than the Swissteco. The two instruments do not cross zero at the same time, the Q*4 instrument appearing to indicate a positive net radiation almost immediately after sunrise, well before the Swissteco. In addition, the two show some diurnal hysteresis with respect to one another. The magnitudes of the differences between instruments and the size of the hysteresis is larger in October. Similar behavior is observed of the Q*4 and TMNR instruments at site 30/32 on these days (figures 3 and 4). The sky during these observations was completely clear except on 8 October when a cirrus overcast prevailed during the day. Note that under the cirrus overcast the differences between instruments was somewhat less. Examination of several cases suggests that the differences increase with season and are greatest under clear skies. The data have been examined to see whether these differences can be related to ambient air temperature, suggesting a temperature dependence in instrument response. No relationship to seasonal or diurnal temperature changes was found.

Another way to examine these data is to compute regression coefficients to predict the net radiation indicated by a test net radiometer from that indicated by a comparison standard, treating negative and positive values separately. The slopes of the regressions will indicate something of the relative response of the two instruments to net longwave and net shortwave radiation. However a quantitative interpretation of instrument characteristics is hampered when one or both instruments does not have equal sensitivity to longwave and shortwave radiation. The indicated net radiation then will depend both on the relative sensitivity to longwave and shortwave within each instrument and on the relative proportions of net longwave and net shortwave in the radiation stream. Comparisons will thus differ according to the radiation environment.

The results of a regression analysis of the KSU comparisons are shown in table 3. REBS Q*4 No 87050 was the comparison standard. REBS Q*4 radiometers differed least from the comparison standard. The offset (B_0) was small, and the slope (B_1) was near 1.0 for both daytime (positive values) and nighttime (negative values). This would be expected for instruments of the same design. Swissteco radiometers had consistently lower daytime B_1 values (about 7%) and larger nighttime B_1 values (about 35%). The zero intercepts for daytime were between about -15 and -21 W m^{-2} and about 11 W m^{-2} for nighttime. Slopes for the TMNR were close to 1, while the daytime intercept was about 33 W m^{-2} and the nighttime intercept similar to that for the Swissteco's.

Since the shortwave calibration constants for the instruments were determined near noon, one would expect that the slope values B_1 would come out near 1.0 and that the intercepts B_0 be near 0 providing that the net radiometers have respectively the same sensitivity to longwave and shortwave. Each instrument should also have the same sensitivity to longwave and shortwave. A departure of B_1 from 1.0 might be attributable to differences in cosine response, thermal response, dome spectral characteristics, sensor plate spectral characteristics (longwave versus shortwave), sensitivity to environmental temperature or wind speed which affect convective losses, and to errors in leveling and calibrating. Departures of B_0, especially for the nighttime observations, is related to differences between radiometers in longwave sensitivity. We observed daytime differences among radiometers of 2 to 6% of full scale even though the radiometers were calibrated a few hours previously over the same surface. In percentage terms the nighttime differences are even larger. This comparison could not determine the true radiative flux or the more accurate radiometer. However, it did strongly suggest that the radiometers have differences between them in sensitivity to short and longwave radiation and that at least some instruments require different calibrations for longwave and shortwave radiation. It also appears from this side by side comparison that we cannot expect daytime net radiation values under these conditions to compare better than 2% and more typically 7% of midday values (even from the same manufacturer); while differences in indicated night time net radiation were at best 15% and typically 75% of the instantaneous flux.

The component radiation observations available at sites 2 and 30 can be used as site comparison standards for examining the behavior of the net radiometers. At site 2 the vegetation was ungrazed prairie grass about 0.5 m high with a closed canopy. All four net radiation components were observed. At site 30 the vegetation was a grazed prairie vegetation of grass about 0.10-0.15 m high and forbs in clumps about .5 m high. The vegetation index at site 30/32 was about 0.3. Observed upwelling solar and thermal radiation at site 30 is subject to some sampling variability due to shadows caused by vegetation clumps. To smooth such irregularities, the albedo at the site was calculated from the observations for each half hour period, smoothed, expressed as a function of solar altitude, and used to compute reflected solar radiation. Observations for solar altitude less than 10 degrees are not used because albedo calculations at such low angles proved unreliable. The thermal emission of the canopy was computed from the surface brightness temperature obtained with an Everest infrared thermometer having a 45 degree look angle. The thermal radiation was also subject to shadow effects, but no adjustments were be made. This caused some scatter in composite net radiation during October when the afternoon net radiation fell below about 300 W m^{-2}. Observations of atmospheric thermal radiation were available at site 38, about 7 km north of site 30. Under clear skies these should be applicable over the whole FIFE study area. For example, incident solar radiation observed on these clear days at sites 38 and 30 agree within 10 W m^{-2} at all times.

Component Net radiation observations at site 2 are plotted against net radometer values in figures 5 to 8. The weather during these 48 hours was generally overcast with periods of scattered cloud. There were several hours of clear sky on the morning of 1 July and during the afternoon of 2 July. Heavy dew occurred during the morning on 1 July. The Swissteco agreed with the component system within about 25 W m^{-2} during mid morning and afternoon. At other times, excepting times of dew fall, the agreement was closer. The two Q*4 instruments indicated net radiation 30 to 60 W m^{-2} higher than the component net radiation during daytime. The Q*3 instrument also exceeded the component measurement by 50 W m^{-2} and also showed rather large excursions (50 W m^{-2}) around the mean relationship. Parameters of the regression equations summarizing the comparison are in table 6. The standard error of the predicted component radiation from the Q*3 instrument over these three days is 18 W m^{-2} while the standard error of the predicted component radiation from the other instruments is about 10 W m^{-2}.

Figure 9 and 10 show plots of component net radiation at site 30 REBS Q*4 No. 87030 an TMNR No. 511 for nine clear sky days in July, August, and October, 1987. The Q*4 net radiation is larger by 30 to 100 W m^{-2} during the daytime and 15 to 25 W m^{-2} at night. The difference increases with season. Parameters of the regression equations fit to data for all nine days are given in table 7. The standard errors of predicted component net radiation for these nine days (spread over three months) are about twice those found in the site 2 comparisons.

From these comparisons with component net radiation and others made by one of us (Fritschen), we conclude that the REBS Q*3 and Q*4 instruments have longwave calibration factors approximately 1.5 times their shortwave calibration factors. To establish this difference more precisely for all radiometers under both day and nighttime conditions we used net shortwave radiation (Snet) observed with component systems to extract apparent net longwave radiation (Lnet') from apparent (or observed) net radiation (NR') from a net radiometer according to

$$\text{Lnet}' = \text{NR}' - \text{Snet} \tag{1}$$

The ratio of "true" to apparent net longwave radiation

$$n = \text{Lnet}/\text{Lnet}' = \text{Lnet}/(\text{NR}'-\text{Snet}) \tag{2}$$

is a more easily comprehended comparison of instrument behavior. Of course, this procedure will force any defect in shortwave response (such as departure from cosine response or non-linearily due to convective losses) into the apparent net longwave radiation. However, after performing the sun/shade calibrations, it is likely that the largest differences among these instruments is not due to their shortwave response characteristics.

The ratio n can be plotted against Snet and Lnet to test for any systematic dependence of n on radiation load and day-night differences. This has been done in figures 11a through 11h for the four radiometers previously discussed from the site 2 comparison. (For these plots, observations during a period of heavy dew fall between 0000 and 0800 CDT have been removed from the data.) The two Q*4 instruments appear to underestimate the net longwave radiation. At night and during overcast skis the value of n averages about 1.45 for #2 and 1.6 for #4. Under clear sky, during the day time, n for both instruments increases to about 2.5. Scattered overcast appears to cause rapid changes in n. For #2 it varies between 1 and 1.7 and for #4 it varies between 1.2 and 2.7. For the REBS

Q*3 the behavior of n is in general similar, however there appears to be a kind of hysteresis. The value of n is about 2 to 2.4 during clear sky conditions and falls to about 1 during the late afternoon under variable cloudiness. Night time value of n are also about 1.5. For the Swissteco the range of value of n calculated from these observations is smaller: 1.0 ±0.1 during night and between about 0.9 and 1.5 during the day. Values during the afternoon are larger than during the morning apparently indicating some hysteresis in instrument output. This hysteresis effect dissappear during the scattered cloud conditions.

The plot of n for Q*4 No 87030 at site 30/32 against Lnet and Snet (figures 12a and 12b) show night time values averaging around 1.5 ± 0.15. Daytime values appear to increase somewhat from around 1.5 to 2.4. The plot of n for TMNR No 511 (figures 13a and 13b) reveals night time values around 1.0 ± 0.1. Day time values range from about 0.9 to 1.2 as net solar radiation increases. That n appears to change with radiation load for the observations at site 30/32 while appearing not to do so at site 2 may be explained by different radiometer behavior under completely clear and scattered cloud conditions. Note that during the several hours of clear sky conditions at site 2, n for the Q*4 instruments rose to 2.5 and for the Swissteco to 1.5. While the explanation for this behavior has not been established it appears to occur to some degree in single dome as well as double dome instruments. We speculate that under scattered cloud the temperature of a net radiometer transducer does not rise so high above ambient air temperature as the 35 or 40 degrees temperature difference which can be observed uninterrupted insolation. At lower temperatures, with reduced convective and other losses, instrument response may be more linear.

From these comparisons we conclude that in the REBS Q*4 and Q*3 instruments the longwave and shortwave sensitivity differ substantially. To address this find REBS developed improved models model Q*5, Q*5.5 and, by late 1989 model Q*6 which comparison with 4-component instrument at the University of WAshington shows good agreement.

The quantitative effect of unequal sensitivity to longwave and shortwave on indicated net radiation can be illustrated using the relation

$$NR' = Lnet/n + Snet. \qquad (3)$$

Both the zero point and the magnitude of daytime as well as nighttime indicated net radiation will be affected by changes in n. For example, assuming an instrument for which n = 1.5, when Lnet = 50 W m^{-2} at the time of zero apparent net radiation, the true net radiation will be 17 W m^{-2}. This effect can be evaluated in the presence of shortwave radiation by expressing daytime Lnet as a linear proportion of Snet. Then writing

$$NR = Snet\ (1 - c) \tag{4a}$$
$$NR' = Snet\ (1 - c/n) \tag{4b}$$

where NR = the true net radiation
NR'= the indicated net radiation
c = Lnet/Snet

For daytime clear sky observations from sites 2 and 30/32 in early July, August, and October the ratio c = 0.20, 0.216, and 0.267 respectively. Values of indicated and true net radiation are given in table 6 for the case of Snet = 600 W m^{-2}. The indicated net radiation may exceed the true net radiation 9 to 12%. The error is smaller when the net longwave radiation is a smaller fraction of total net radiation, as when the sky is overcast or near the summer solstice.

One approach to adjusting all net radiometer observations to a common standard is to compare examples of all the net radiometers to the new Q*6. This was done in January and March 1990 at the University of Washington. Parameters of the comparison regression equations are presented in tables 5a and 5b. However, it must be noted that the parameters of such equations must be applied with some caution as they apply only when the proportion of longwave and shortwave approximate that under the calibrating conditions. Observe, for example, differences in the parameters between tables 5a and 5b which may be due to season.

These parameters have been applied to the site 2 and site 30/32 observations. Plots of the component net radiation against the regression corrected values are given in figures 14a through 14d and 15a and 15b. These graphs may be compared with the uncorrected situation by means of the regression parameters in tables 7 and 8 for "Corrected(R)". The slopes are closer to 1:1 and the intercepts generally closer to zero then in the uncorrected case.

Another approach which may be used when observations of net shortwave radiation are available is to disaggregate the apparent net radiation according to equation 1, correct the apparent net longwave (equation 3) with the values of the ratio n established for the instrument, and recombine the corrected net longwave with the net shortwave. The ratio n may be taken as a constant, or with better understanding of how n changes with net shortwave radiation under clear sky conditions, expressed as a function of net shortwave radiation and some surrogate for instrument heating such as elapsed time since a shaded condition. Here, in the absence of more complete information we have taken n as a constant which appears to minimize the difference between apparent and observed net longwave radiation. A single value was adopted for daytime and night time conditions even though examination of figures 11 and 12 suggest time variable values might be suitable. For the Swissteco and TMNR, values near 1.0 and 0.95, respectively, are reasonable.

A value near 1.5 is appropriate for the REBS Q*3 and Q*4 instruments, however comparing figures 11c and 11d with 11g and 11h suggest 1.45 and 1.6 fit the two model Q*4 instruments in the site 2 data. These values were employed to develop the graphs of figures 16a-16d and (L) corrections in table 7. For the site 30/32 comparison a value of n changing with season will reduce the variability that appears in the data (figure 12). Values of 1.45, 1.55, and 1.75 for July, August, and October observations were used in developing figures 17 and 18 and (L) corrections in table 8. Night time values of n do not seem to vary with season.

Neither correction scheme improves the standard error of predicted component net radiation from the net radiometer observations. The standard error of predicted net radiation is about ±20 W m^{-2} in the site 30/32 data for four observation periods and about ±11 W m^{-2} for one observation period at site 2 for the Q*4 and Swissteco instruments. The Q*3 instrument showed nearly twice this scatter. However, these correction schemes are intended to adjust values to the mean of the site comparison standard. A regression of site comparison standard against corrected net radiation values should have a slope of 1 and intercept of 0. Departures from this ideal can still lead to good predicted values if slope and offset compensate. The regression correction method does not seem to improve the site 2 observations. The regression corrected values differ from the component observations by 4 to 10%. On the other hand, when corrected by the longwave disaggregation method, they differ less than 3% from the component observations. At site 30/32 the regression correction and longwave disaggregation correction methods appear to be equally effective. The difference between the values corrected by either method and the component net radiation is less than 3%. Agreement between longwave corrected TMNR 511 and REBS Q*4 observations at site 30/32 is within 1% (figure 18a). On the other hand, the regression correction applied to these same instruments produces excessively large Q*4 values at low positive net radiation (figure 18b). This difference is about 25% at 200 W m^{-2} net radiation. It is not clear why the regression correction method is less satisfactory in this comparison and at site 2.

In conclusion, uncorrected net radiation observations made with calibrated Swissteco and TMNR net radiometers agree within at least 3% of component observations, taken as site standards. This level of agreement was achieved at three separate sites, with three different investigators: site 2, site 30/32, and the University of Washington. Observations made with the REBS Q*3 and Q*4 instruments need to be corrected. Both the regression method or the longwave disaggregation method appeared useful for these observations. Agreement of the corrected observations to within 3% of the site comparison standard was be achieved. The longwave disaggregation method, avoids the interacting effects of instrument sensitivity to shortwave and longwave and the proportions of shortwave and longwave in the radiation stream. It also leads to better agreement between corrected Q*4 and TMNR observations. However, it requires an independent measurement of local net shortwave radiation and may not be generally applicable.

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Table 1. Net Radiation instruments used by Fife Investigators. The institutional abbreviations are ARS: U.S.D.A. Agricultural Research Service Hydrology Laboratory; FSU: Florida State University; IH: Institute of Hydrology; KSU: Kansas State University; NCAR: National Center for Atmospheric Research; UD: University of Delaware; UNL: University of Nebraska, Lincoln; USGS: U.S. Geological Survey; UW: University of Washington.

P.I.	1987		1988		1989	
	Inst.	Sites	Inst.	Sites	Inst.	Sites
ARS	REBS Q*4	32	--		--	
FSU	4-Instr.	2, 38	4-Instr.		4-Inst.	
IH	Didcot	26	--		?	
KSU	REBS Q*4	6, 8, 10, 12, 14	REBS Q*4		REBS Q*5	
NCAR	REBS Q*3	...	REBS Q*3		REBS Q*3	
UD	TMNR	30	--		--	
UNL(1)	REBS Q*4 Swissteco	16	REBS Q*4 Swissteco		REBS Q*5 Swissteco	
UNL(2)	REBS Q*3	25,...	--		--	
USGS	Swissteco	22, 24, 28	--		--	
UW	REBS Q*4	20, 34, 36, 40, 42, 44	REBS Q*4		REBS Q*5	

Table 2. Approximate Mean Difference of Net Radiation between Comparison Standard (REBS model Q*4 No 87050) and Other Net Radiometers [W m^{-2}]

Instrument	Daytime	Nighttime
Standard - TMNR 511	+30	+10
Standard - Swissteco (7377)	+55	+25
Standard - Swissteco (7337)	+55	+25
Standard - Swissteco (6850)	+50	+30
Standard - REBS Q*4 (87060)	+15	+10
Standard - Micromet Q*3 (86029)	+15	0

Table 4. Comparison of net radiometers against the University of Nebraska radiometer (REBS #87050) over a 24 hour period

	Daytime values					Nighttime values				
Radiometer	r^2	B_0*	S.E.	B_1*	S.E.	r^2	B_0*	S.E.	B_1*	S.E.
Univ. Del. TMNR 511	0.96	-32.69	8.09	1.01	0.02	0.94	-12.94	0.66	0.98	0.02
Univ. Neb. Swiss. 7337	0.95	-14.93	7.98	0.93	0.02	0.98	-10.31	0.62	1.41	0.02
USGS Swiss. 7377	0.96	-21.14	7.14	0.94	0.02	0.98	-10.66	0.57	1.33	0.02
KSU Swiss. 6850	0.96	-17.23	7.44	0.94	0.02	0.98	-10.70	0.49	1.35	0.01
UK Didcot DRN 301	0.98	22.17	4.70	0.91	0.01	0.38	- 1.15	4.44	1.25	0.14
NCAR Micromet 86029	0.99	-22.30	4.31	1.01	0.01	0.98	- 5.81	0.28	0.82	0.01
UW REBS 87060	0.98	-05.52	5.08	0.98	0.01	0.95	- 3.78	0.66	1.04	0.02

$*Y(w/m^2) = B_0 + B_1$ (REBS #87050)

Table 5a. Comparison of net radiometers for periods of positive and negative net radiation for three days in January, 1990??. REBS Q*6 (89105) is plotted on the y-axis, other instruments are on the x-axis of the equation $Y=B_0+B_1$(REBS No 98105). [W m^{-2}]

Instrument	Time Period	B_1	B_o	r^2
REBS Q*3	positive	0.950	-8.96	0.995
	negative	1.346	-4.170	0.990
REBS Q*4	positive	0.840	-21.282	0.978
	negative	1.165	-7.570	.929
REBS Q*5	positive	1.009	-2.142	.995
	negative	0.996	-0.808	0.995
REBS Q*5.5	positive	1.004	-1.556	0.997
	negative	1.003	-1.412	0.993

Table 5b. Comparison of net radiometers for periods of positive and negative net radiation from March 12 to March 28, 1990. REBS Q*6, SN 89105 is plotted on the Y-axis, other instruments listed are on the X-axis of the equation
$Y=B_o+B_1(\text{REBS No } 89105)$ [W m^{-2}].

RADIOMETER TYPE SERIAL NUMBER	PERIOD	B_1	B_o	R^2	No.
REBS Q*6	pos.	1.0002	3.1606	0.9987	449
89104	neg.	1.0330	-0.2302	0.9991	631
REBS THR as Q*6	pos.	1.0000	0.5388	0.9949	425
89001	neg.	1.0420	0.1075	0.9946	631
REBS Q*5.5	pos.	0.9535	1.9212	0.9952	483
89053	neg.	1.0115	-0.2663	0.9936	631
REBS Q*5	pos.	0.9474	0.9856	0.9961	483
87059	neg.	0.9924	-0.3806	0.9954	631
REBS Q*4	pos.	0.8971	1.8470	0.9814	416
87058	neg.	1.4608	-0.5780	0.9955	589
REBS Q*3	pos.	0.9013	-4.3992	0.9886	483
86std2	neg.	1.2964	-2.4343	0.9899	631
SWISSTECO	pos.	1.0361	-4.9152	0.9945	429
8039	neg.	0.9080	-0.0208	0.9878	597
SWISSTECO	pos.	1.0340	-10.9749	0.9987	32
8183	neg.	0.9480	-3.1357	0.9808	114
THORNTHWAITE	pos.	0.9827	1.6743	0.9931	423
MNR500	neg.	1.0437	3.2954	0.9378	631
MICROMET INST.	pos.	0.7963	-1.0629	0.9681	479
X106	neg.	1.0732	4.2139	0.9044	623

Table 6. Comparison of Indicated and True Net Radiation for Different Proportions of Shortwave and Longwave Radiation when Net Radiometer Calibration for Shortwave and Longwave are in the ratio Snet/Lnet = 1.5. Net shortwave in each case is 600 W m^{-2}, c is the ratio of net longwave to net shortwave in the actual net radiation. [W m^{-2}]

c	NR	NR'	% error
0.200	480	522	8.8
0.216	470	514	9.4
0.267	440	493	12.0

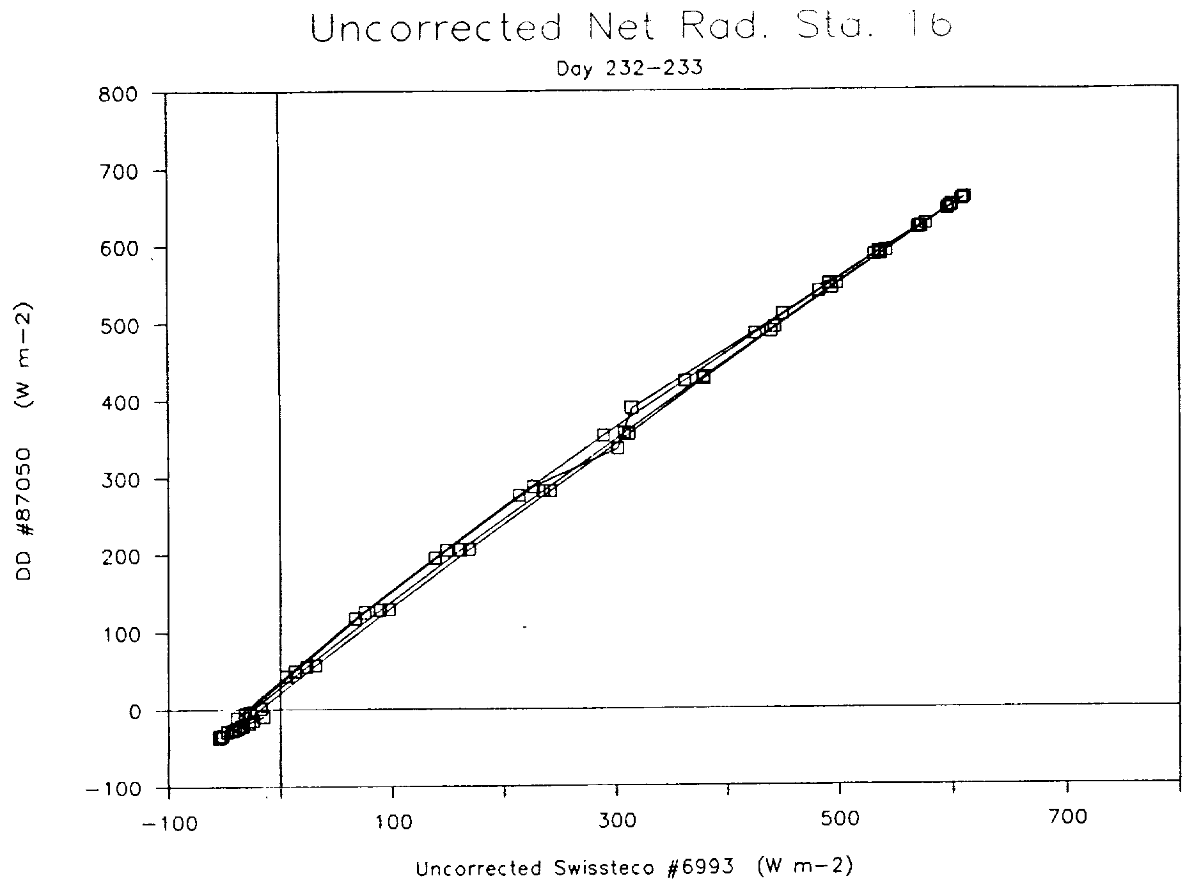


Figure 1

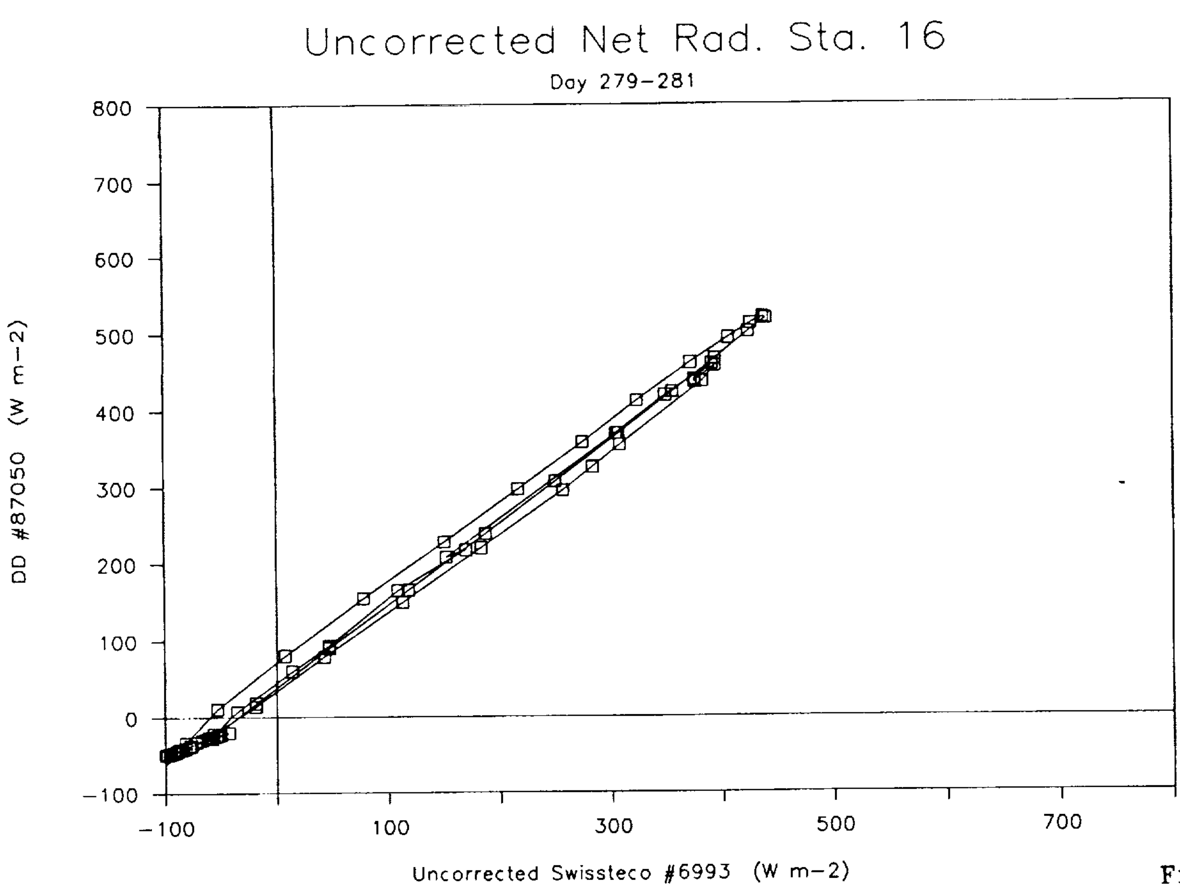


Figure 2

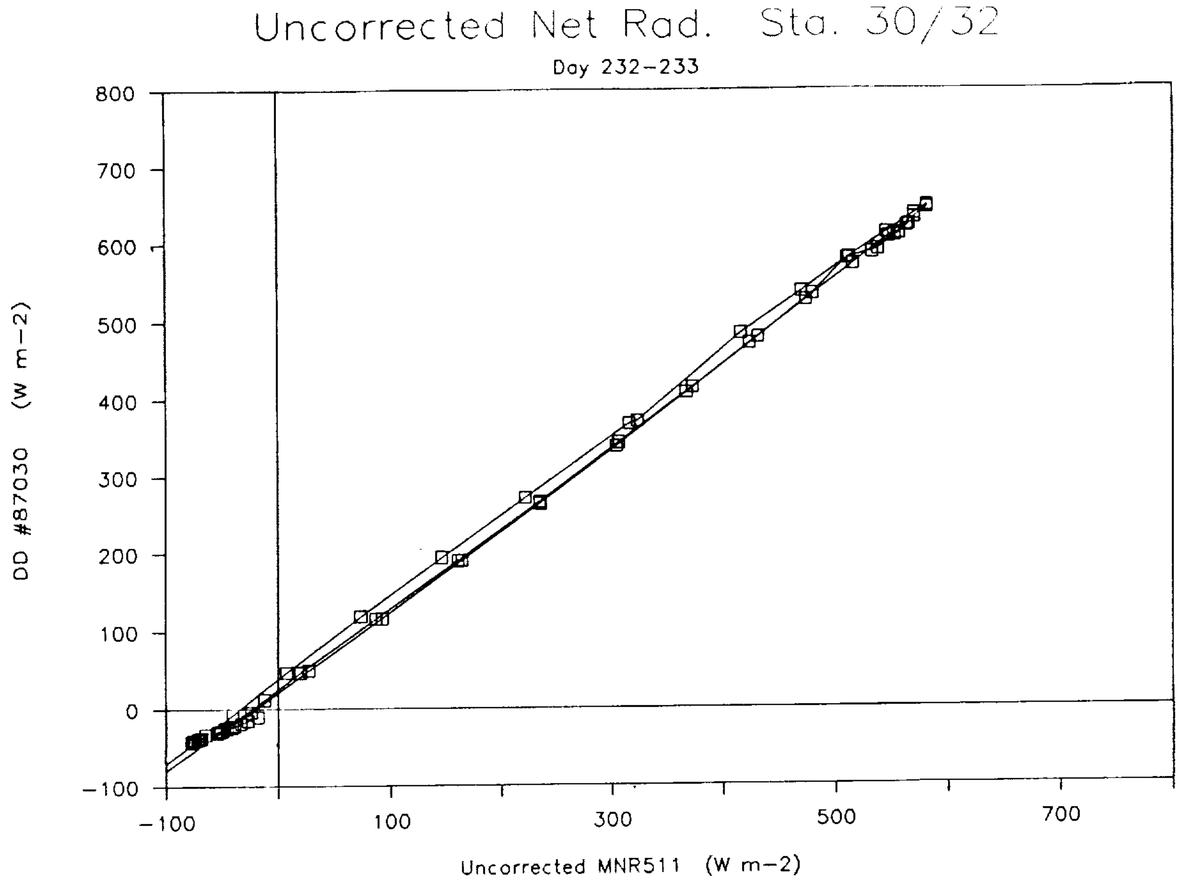


Figure 3

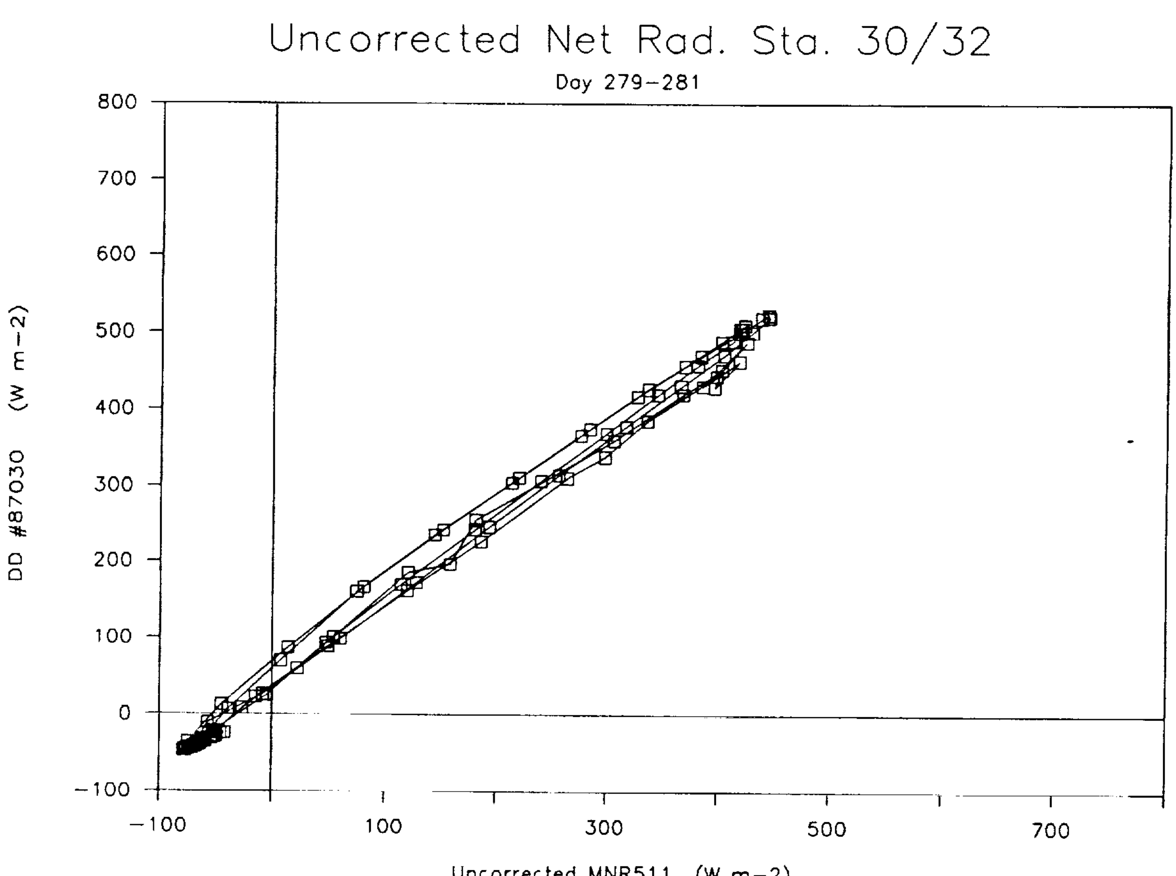


Figure 4

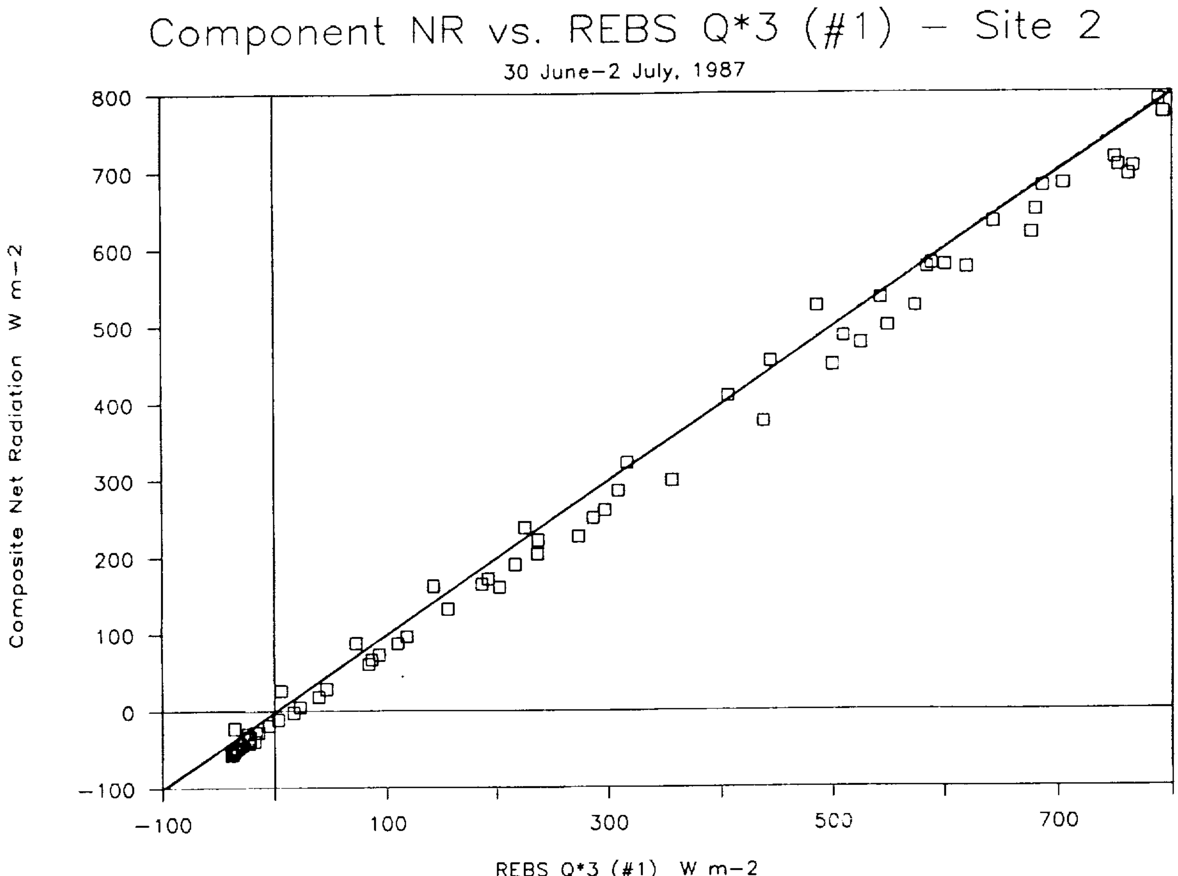


Figure 5

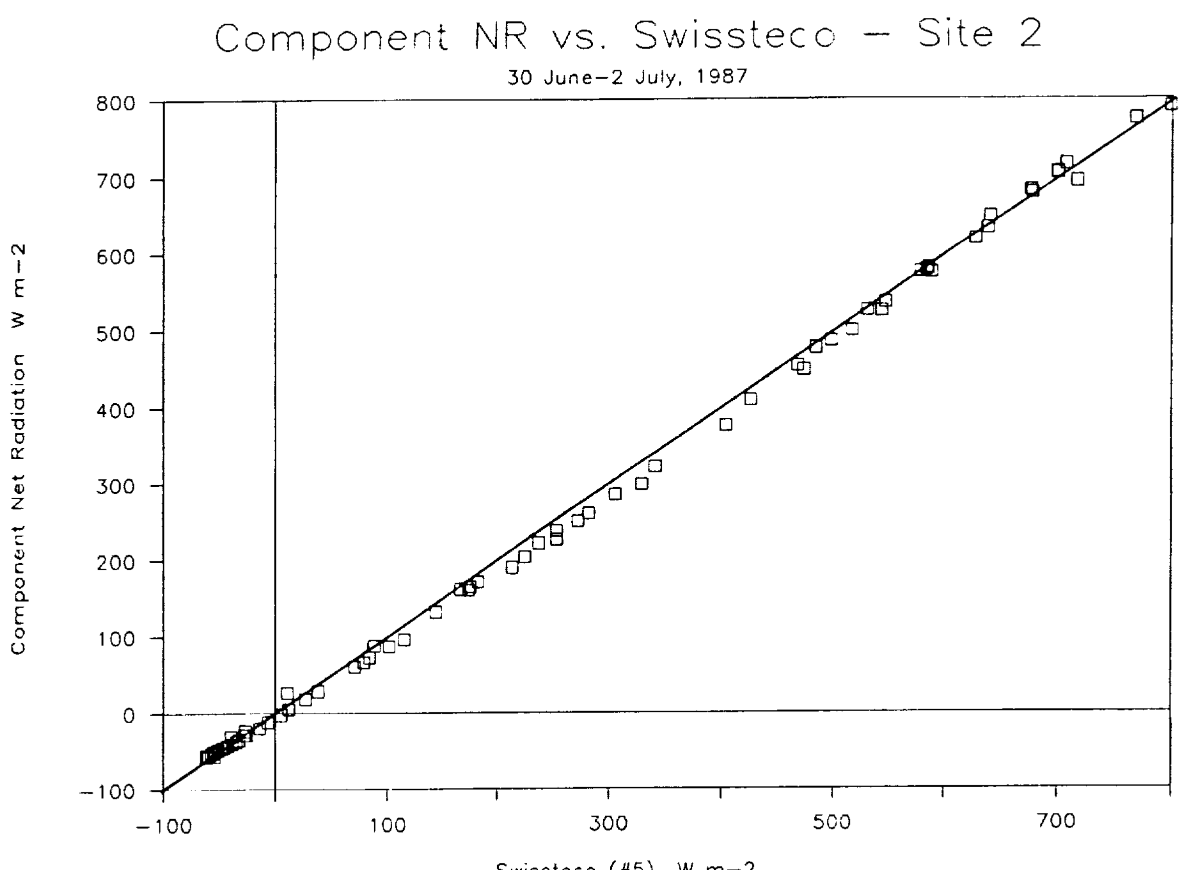


Figure 6

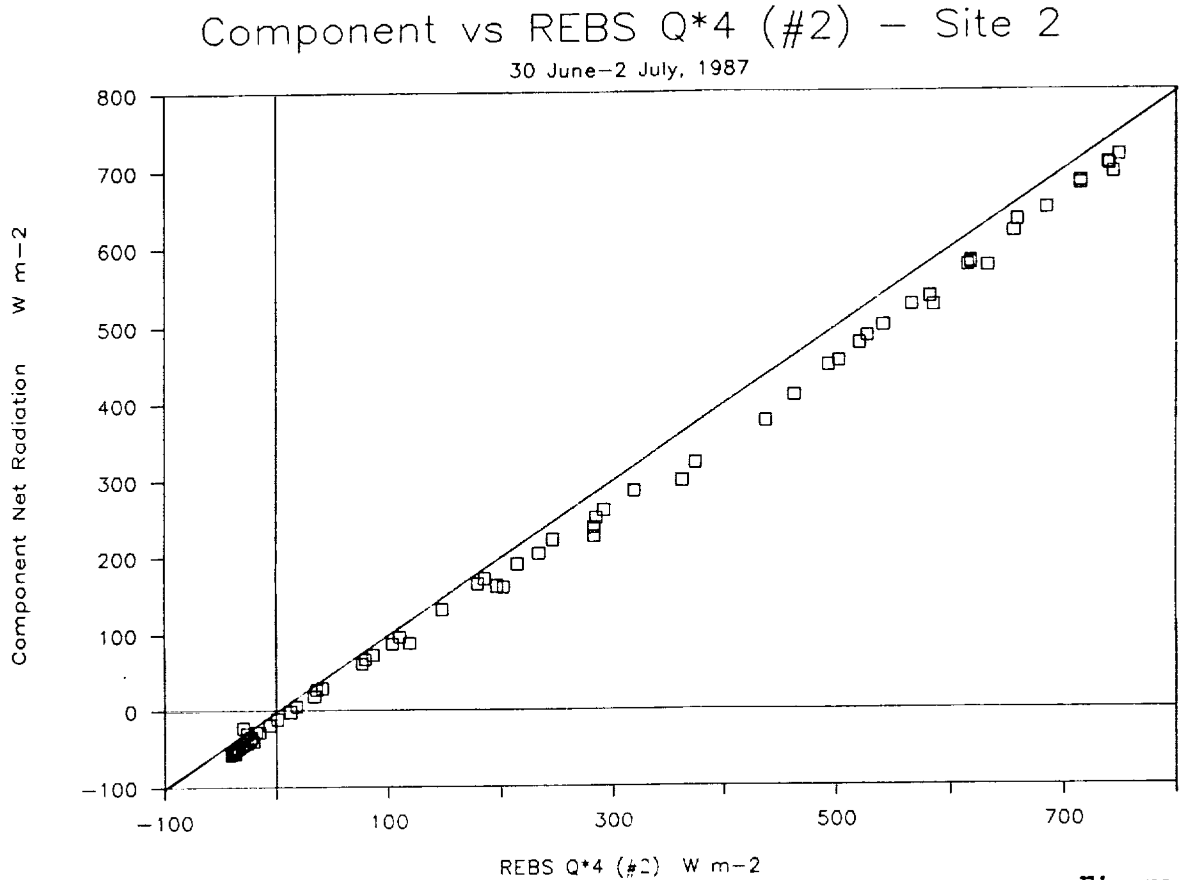


Figure 7

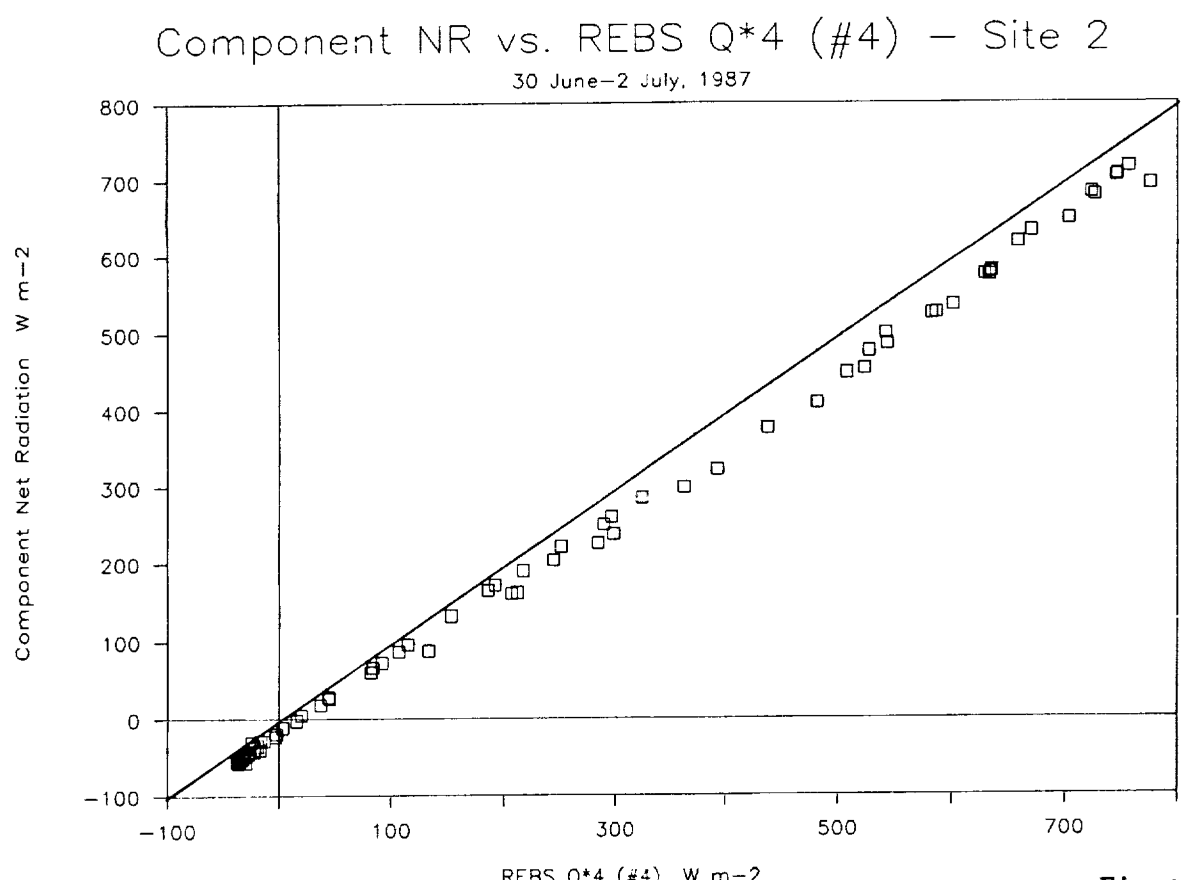


Figure 8

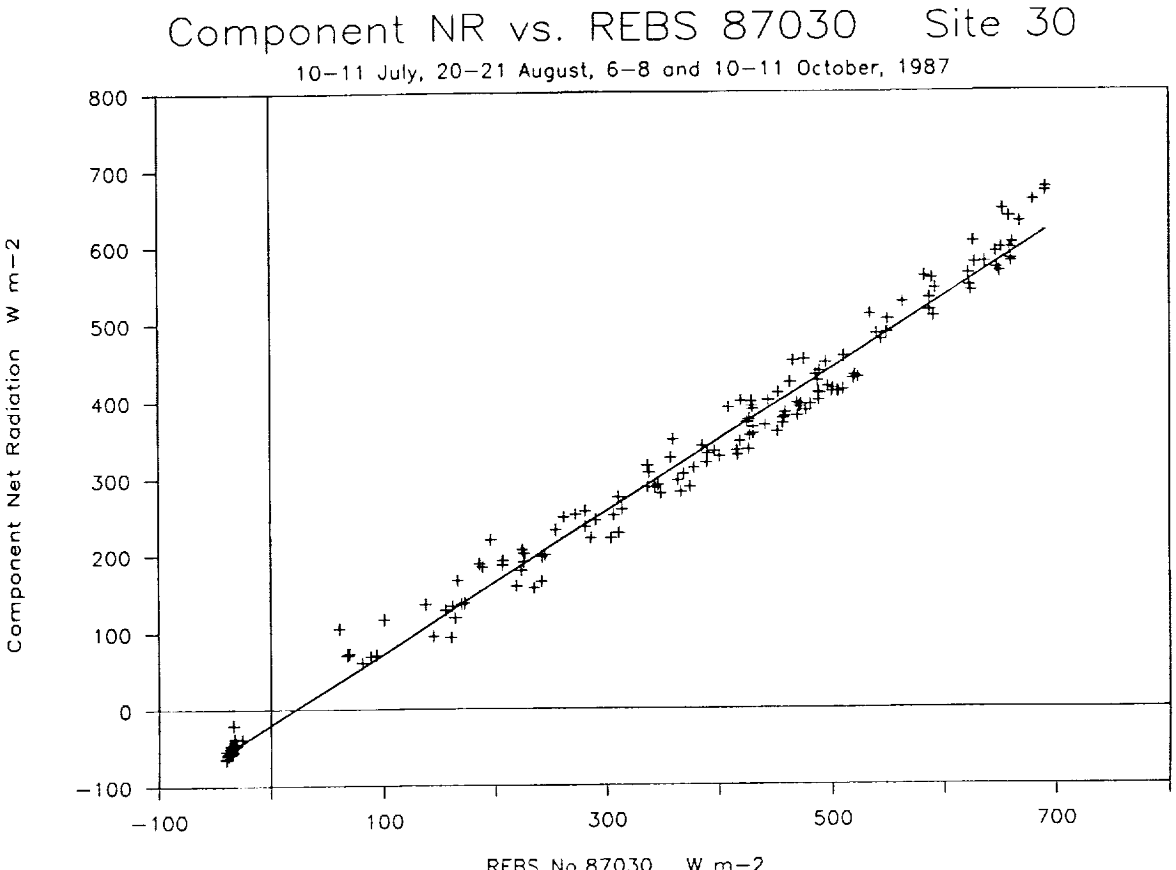


Figure 9

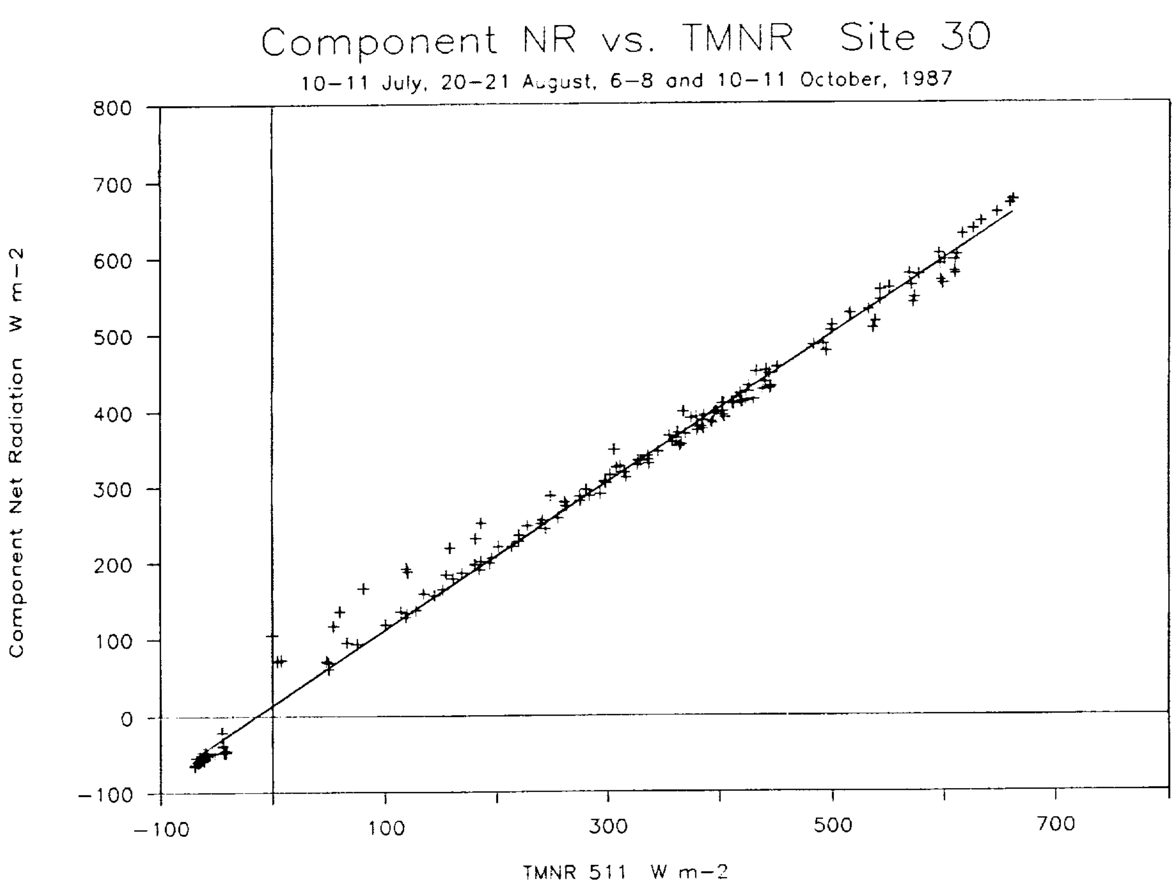


Figure 10

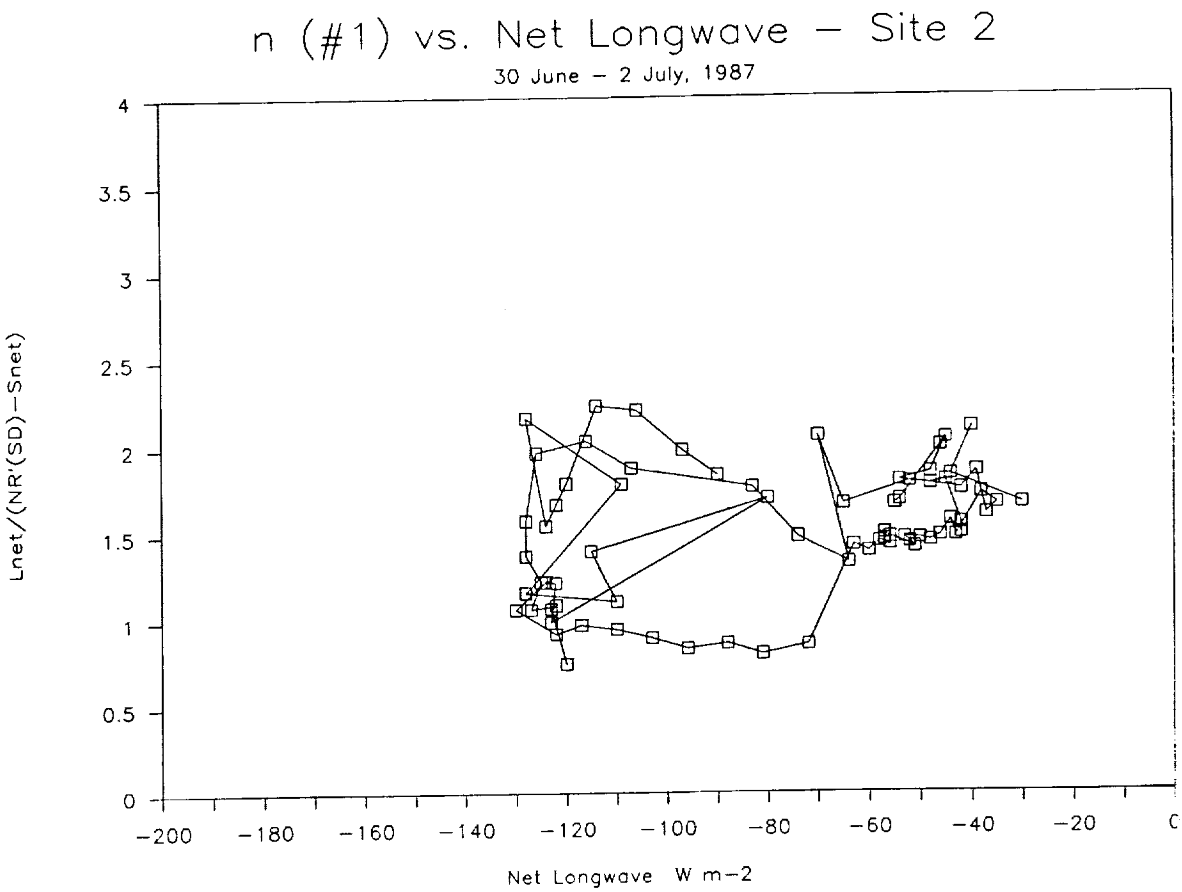


Figure 11a

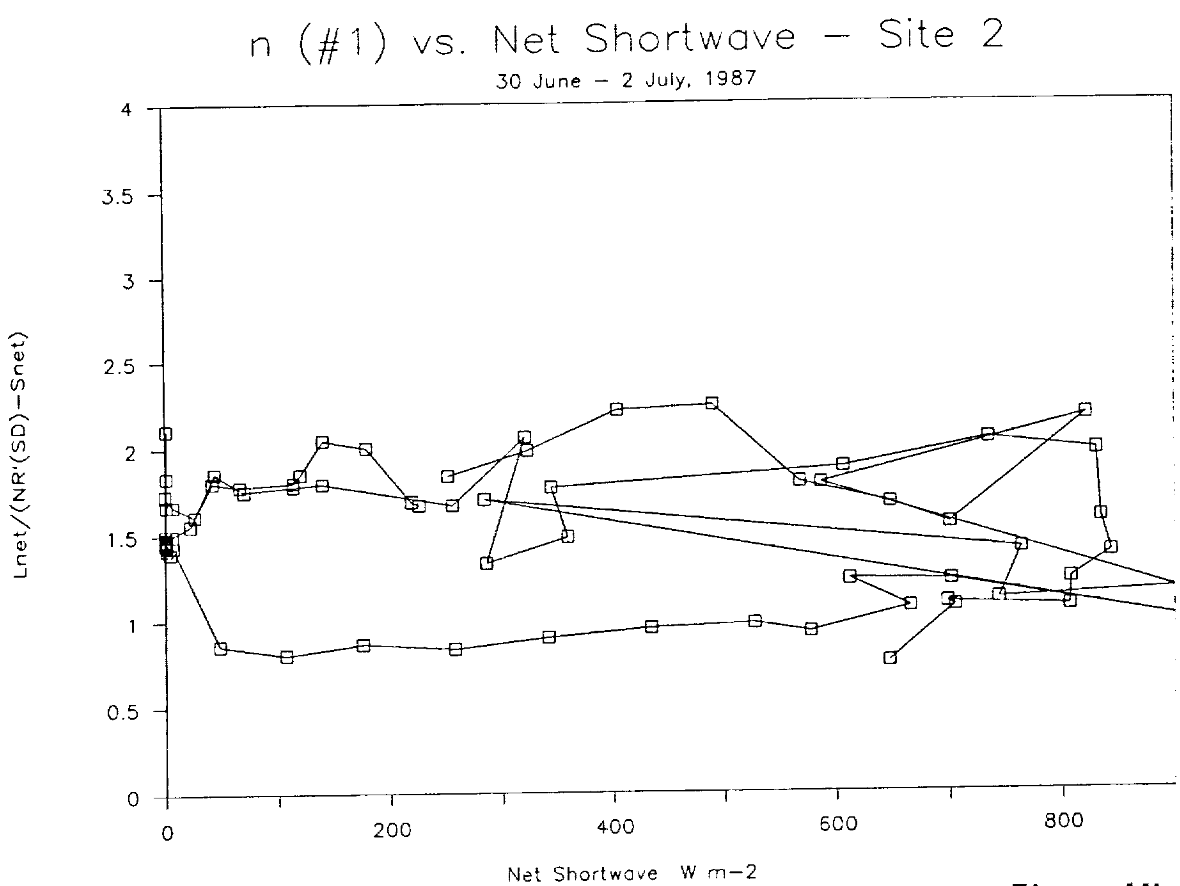


Figure 11b

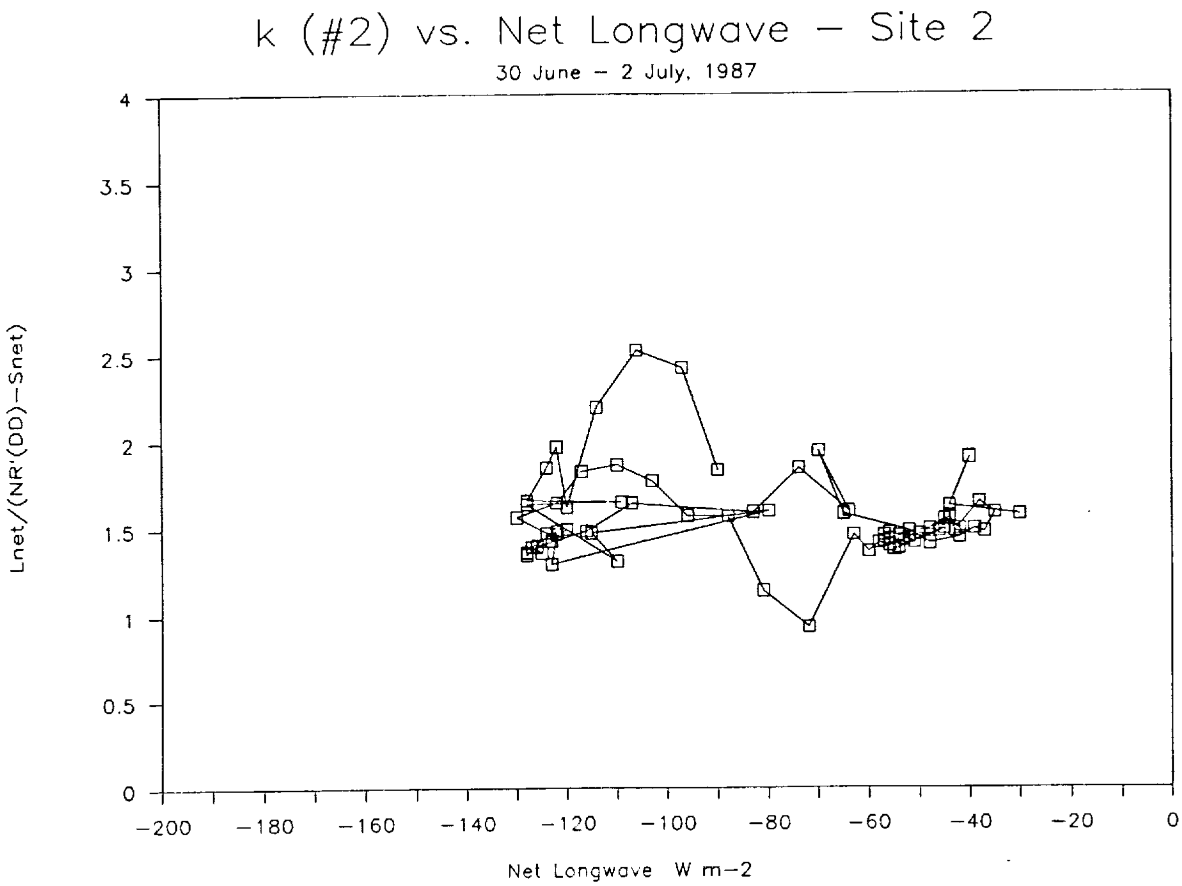


Figure 11c

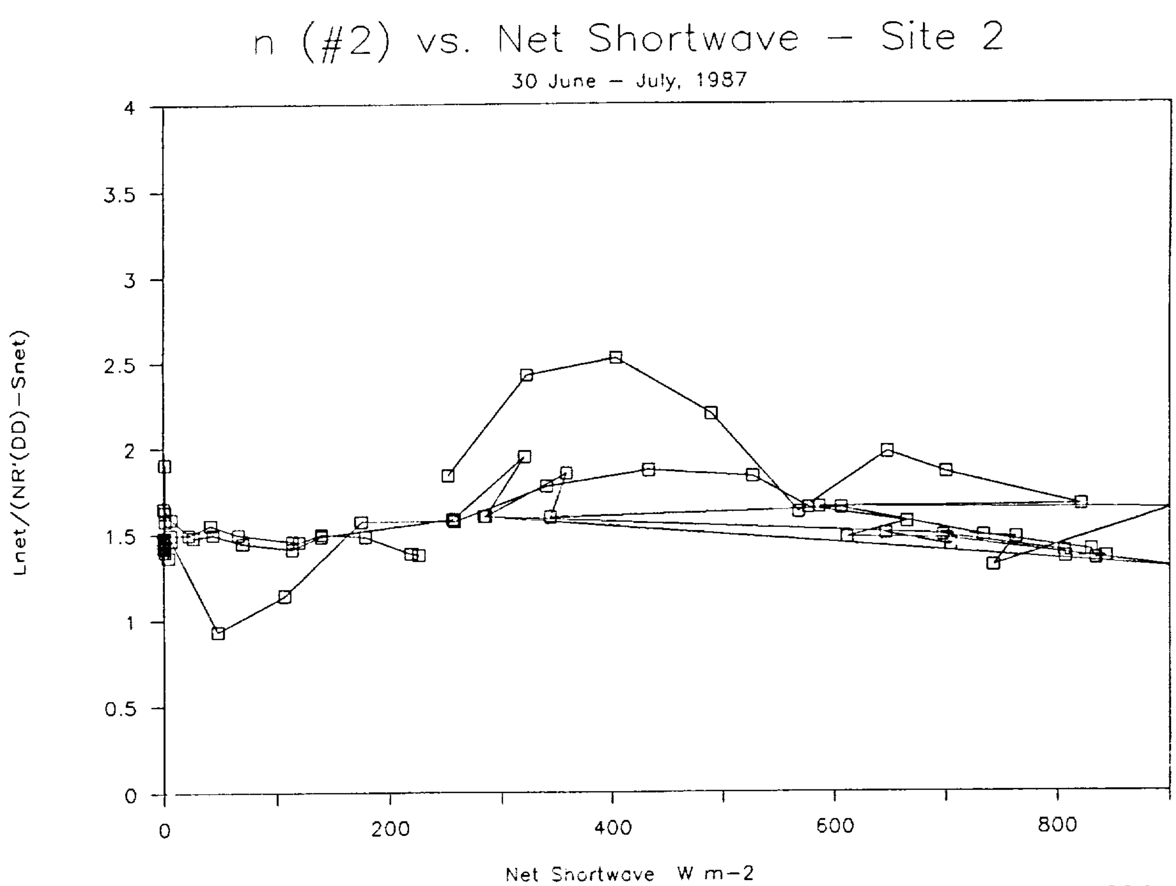


Figure 11d

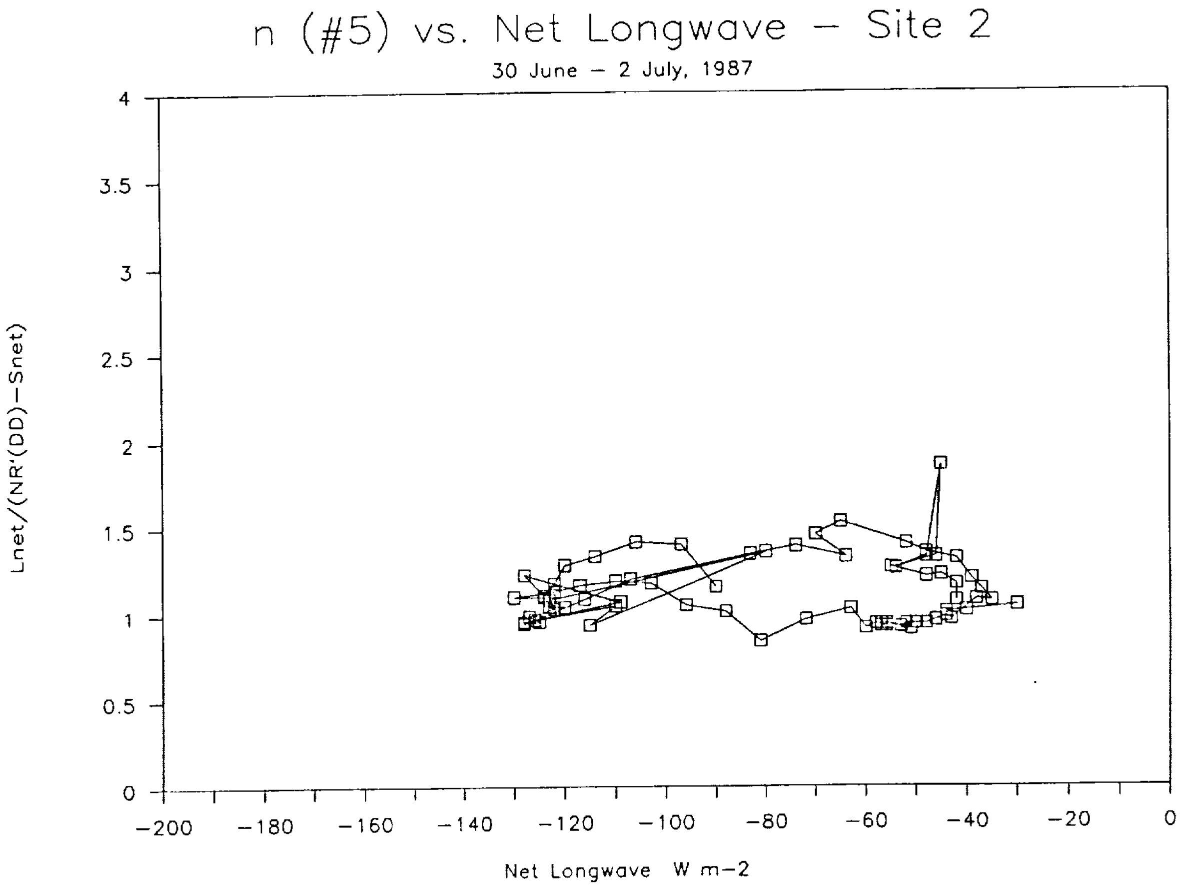


Figure 11e

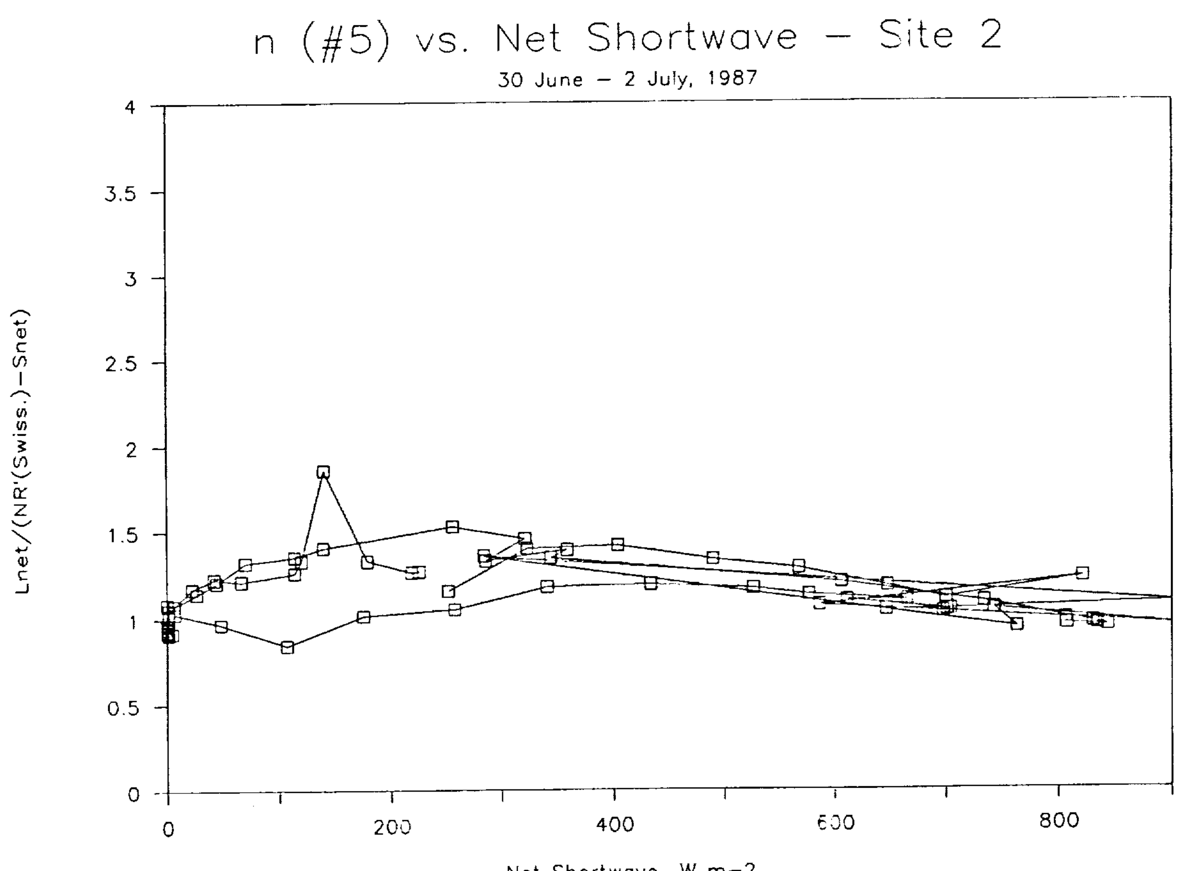


Figure 11f

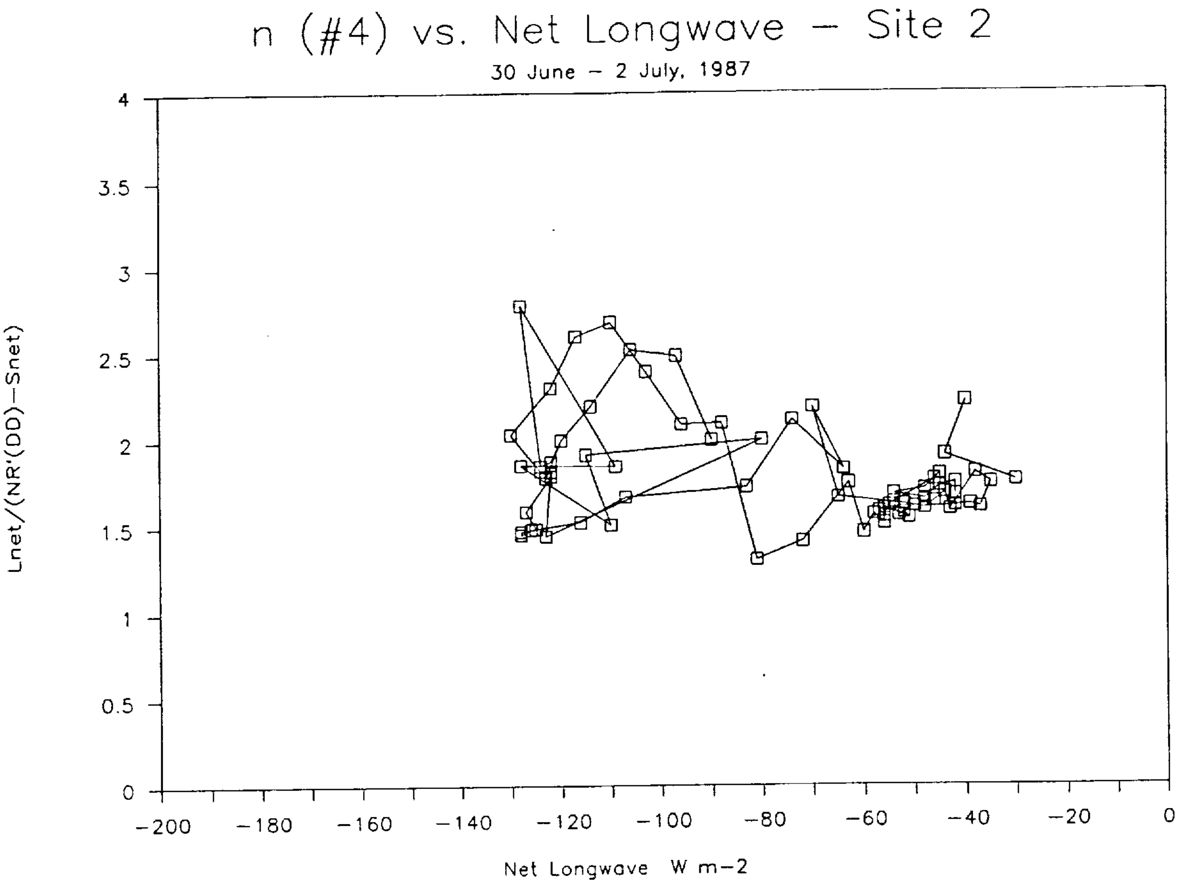


Figure 11g

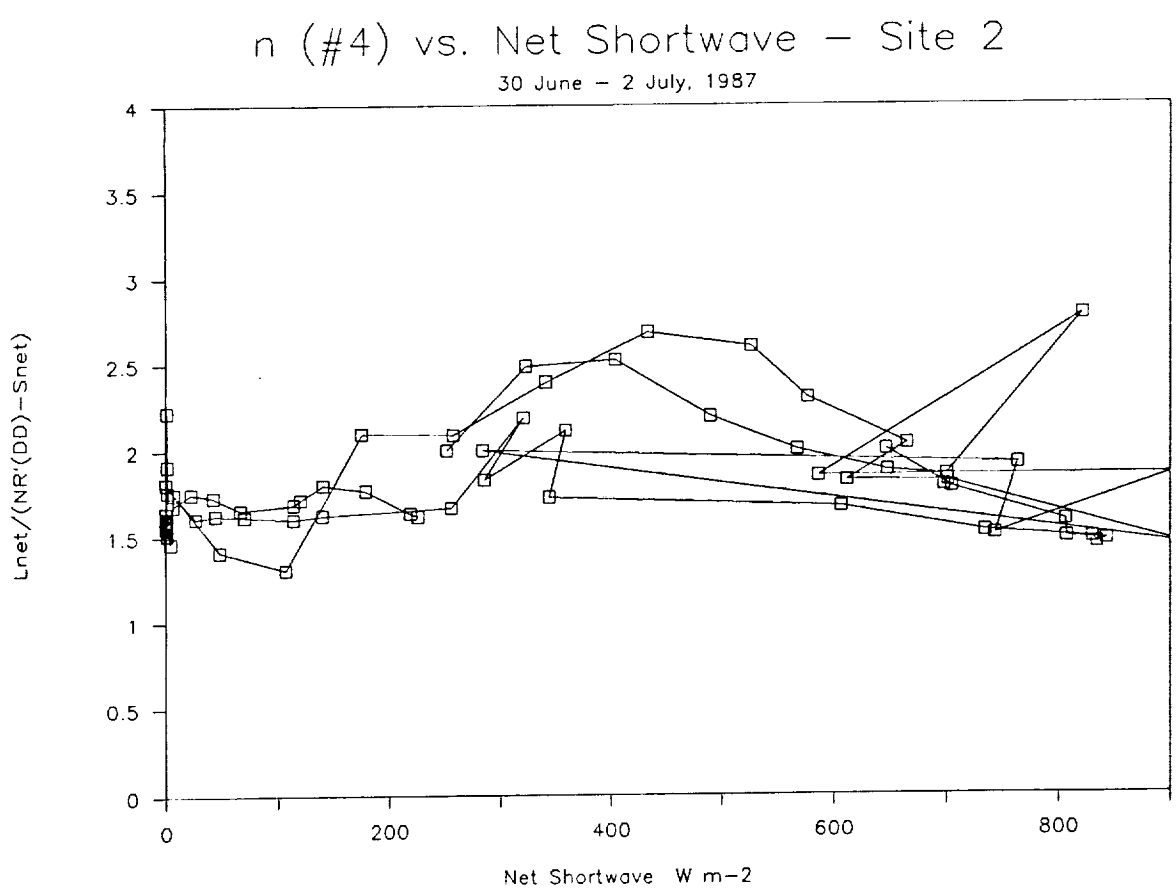


Figure 11h

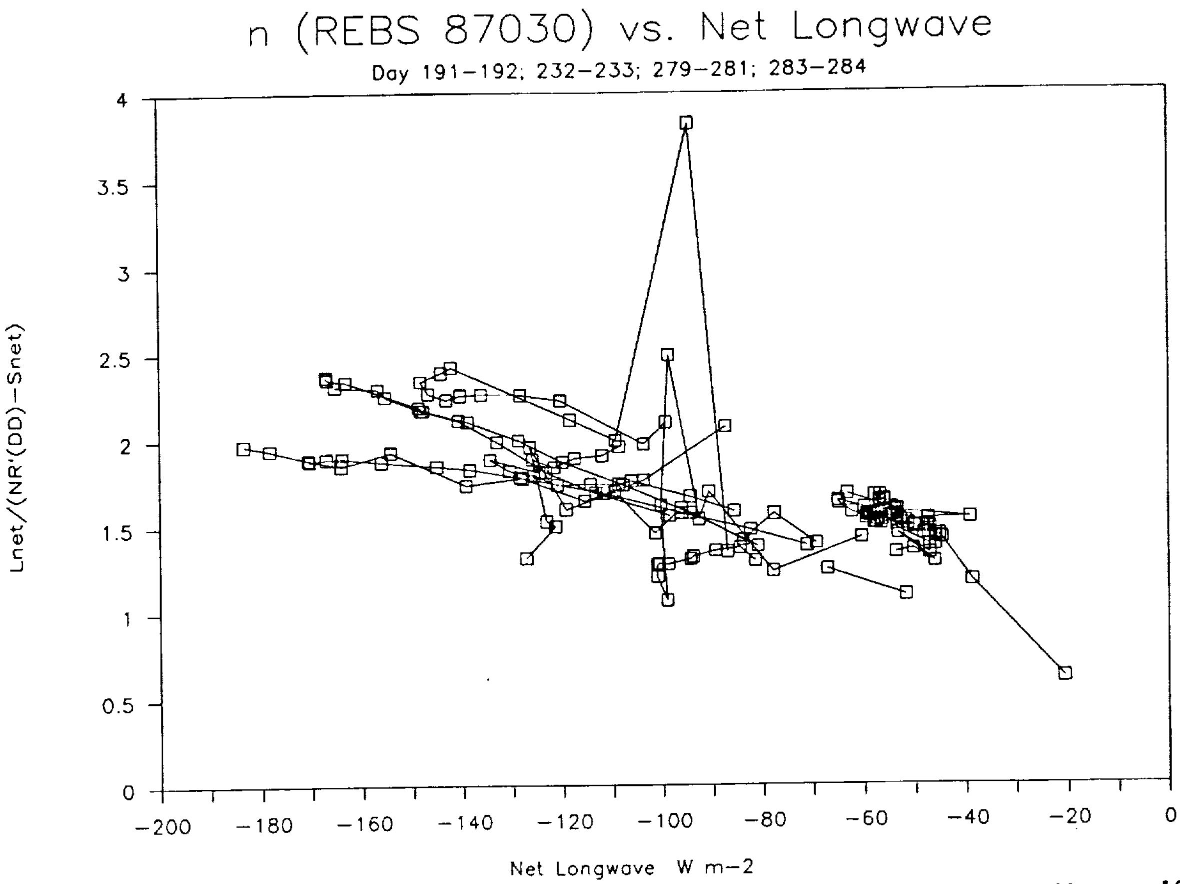


Figure 12a

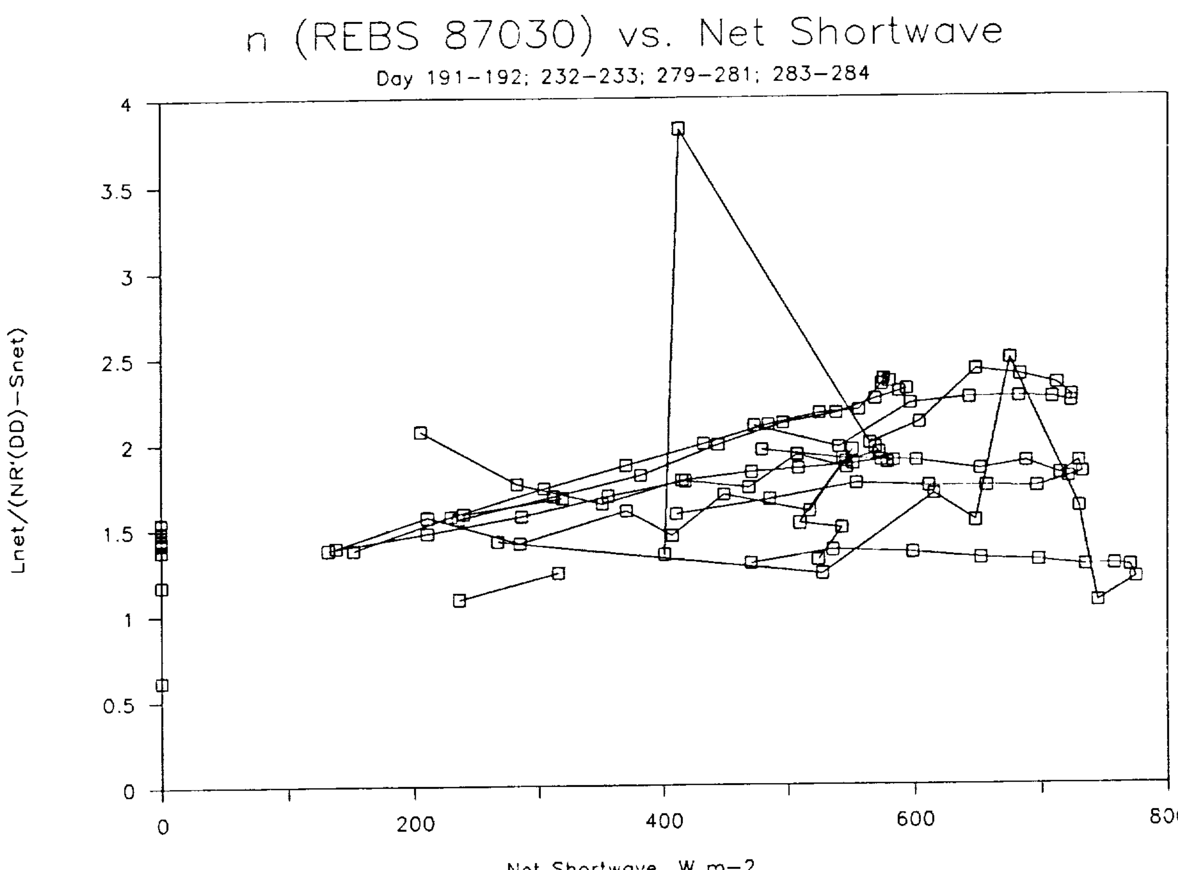


Figure 12b

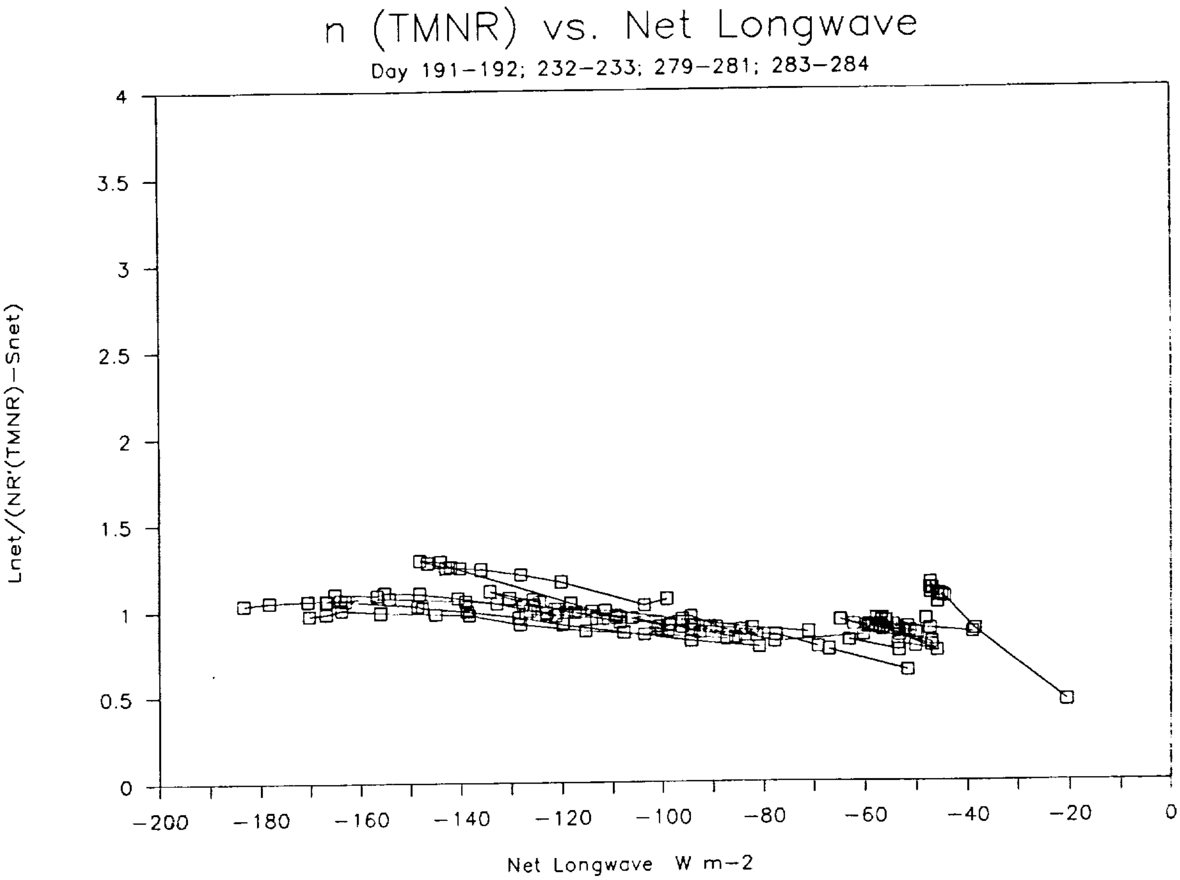


Figure 13a

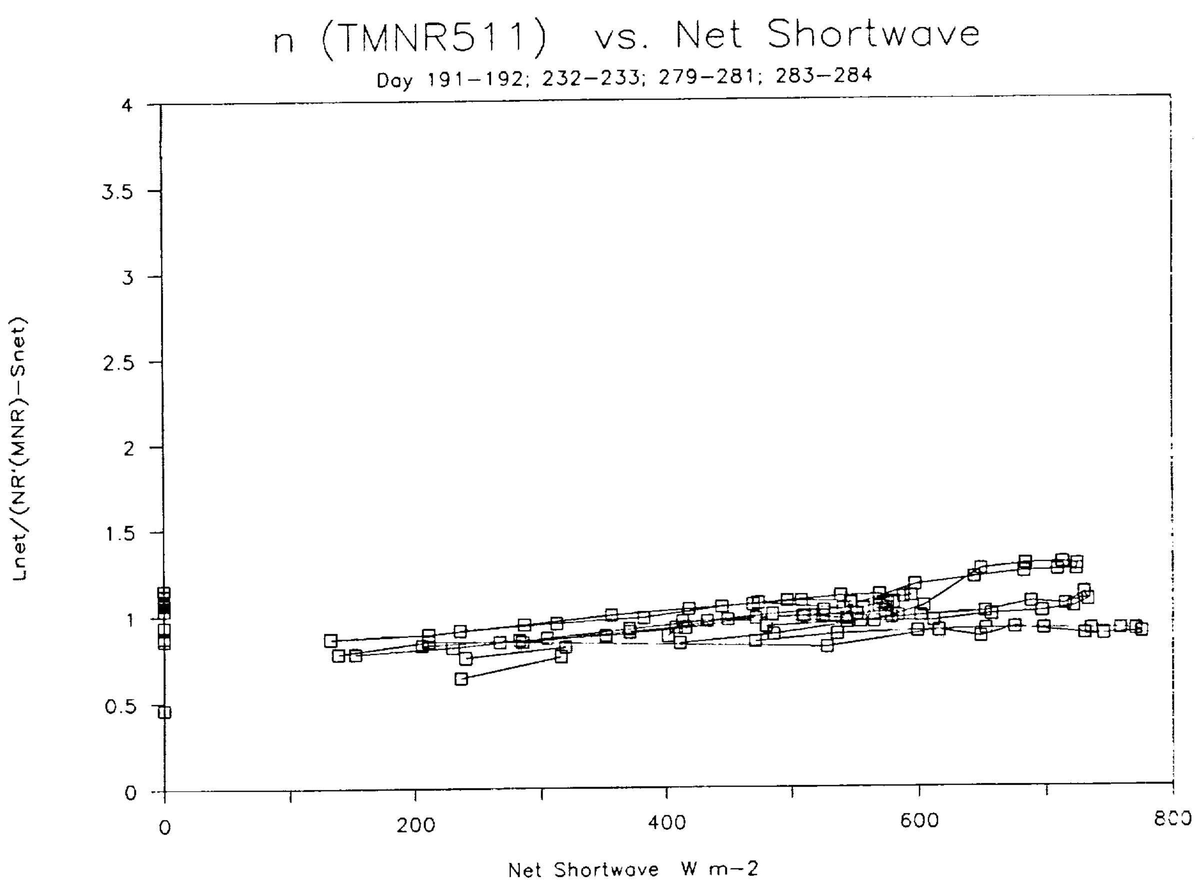


Figure 13b

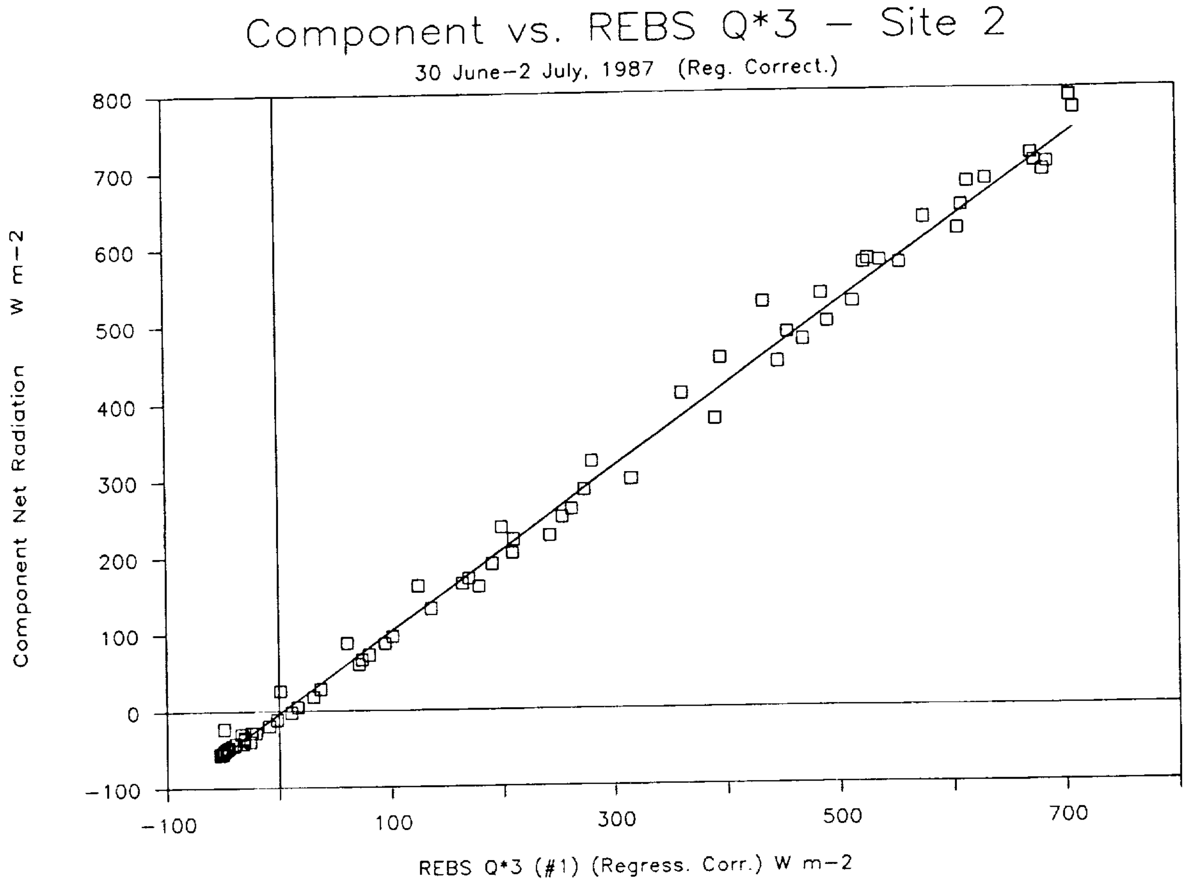


Figure 14a

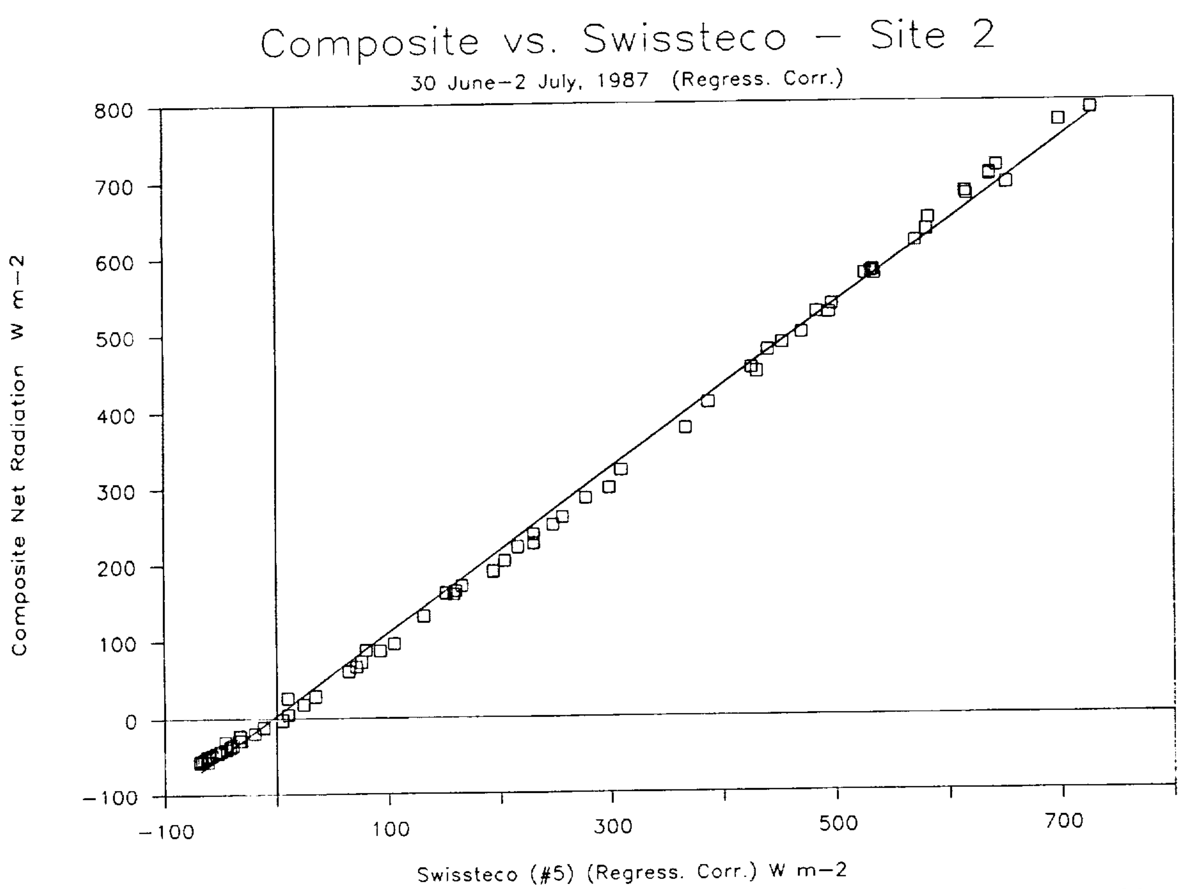


Figure 14b

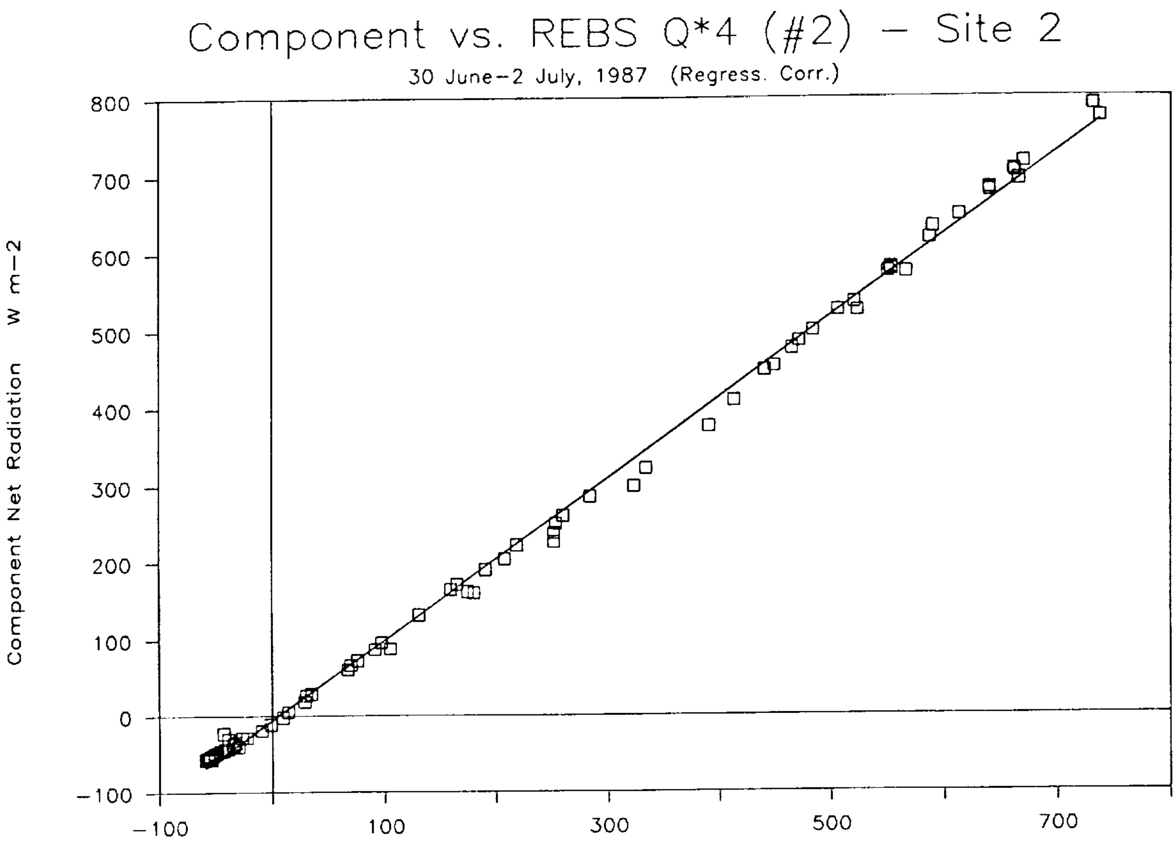


Figure 14c

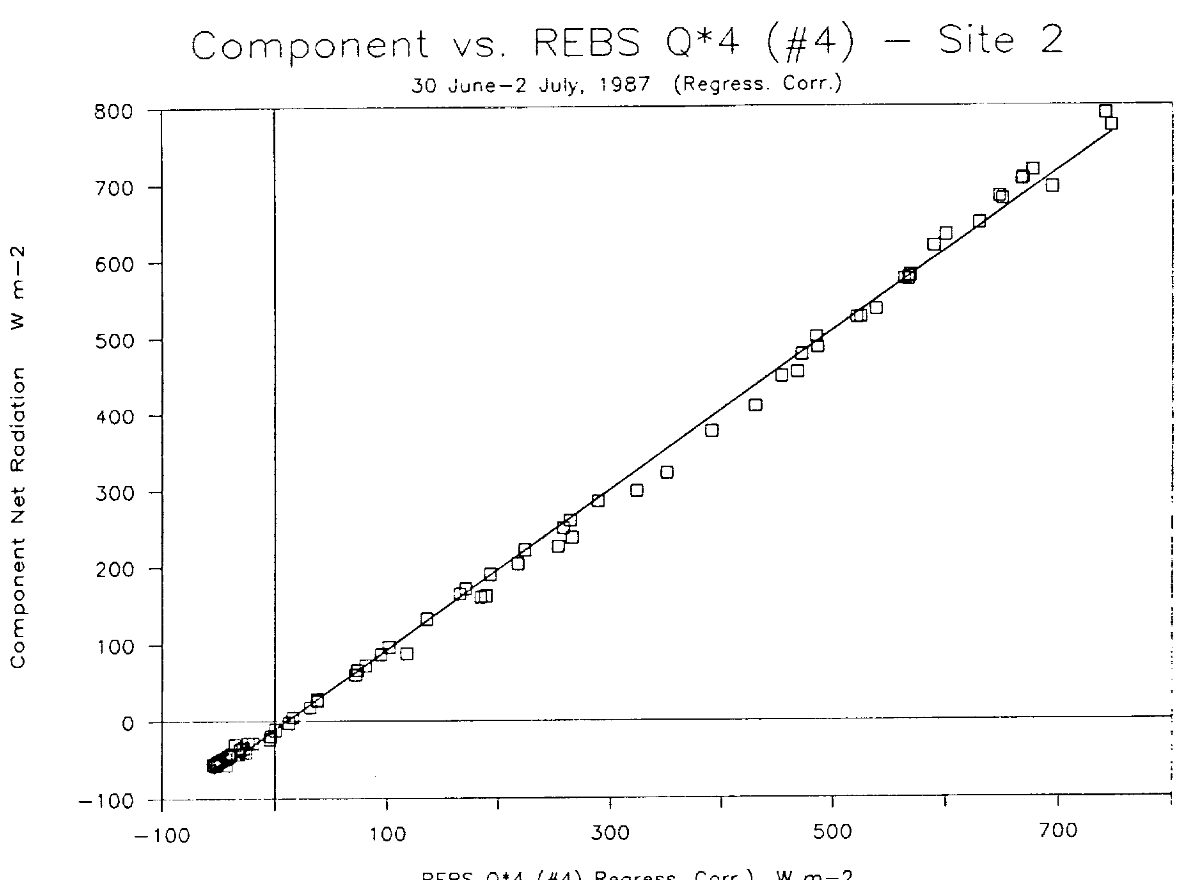


Figure 14d

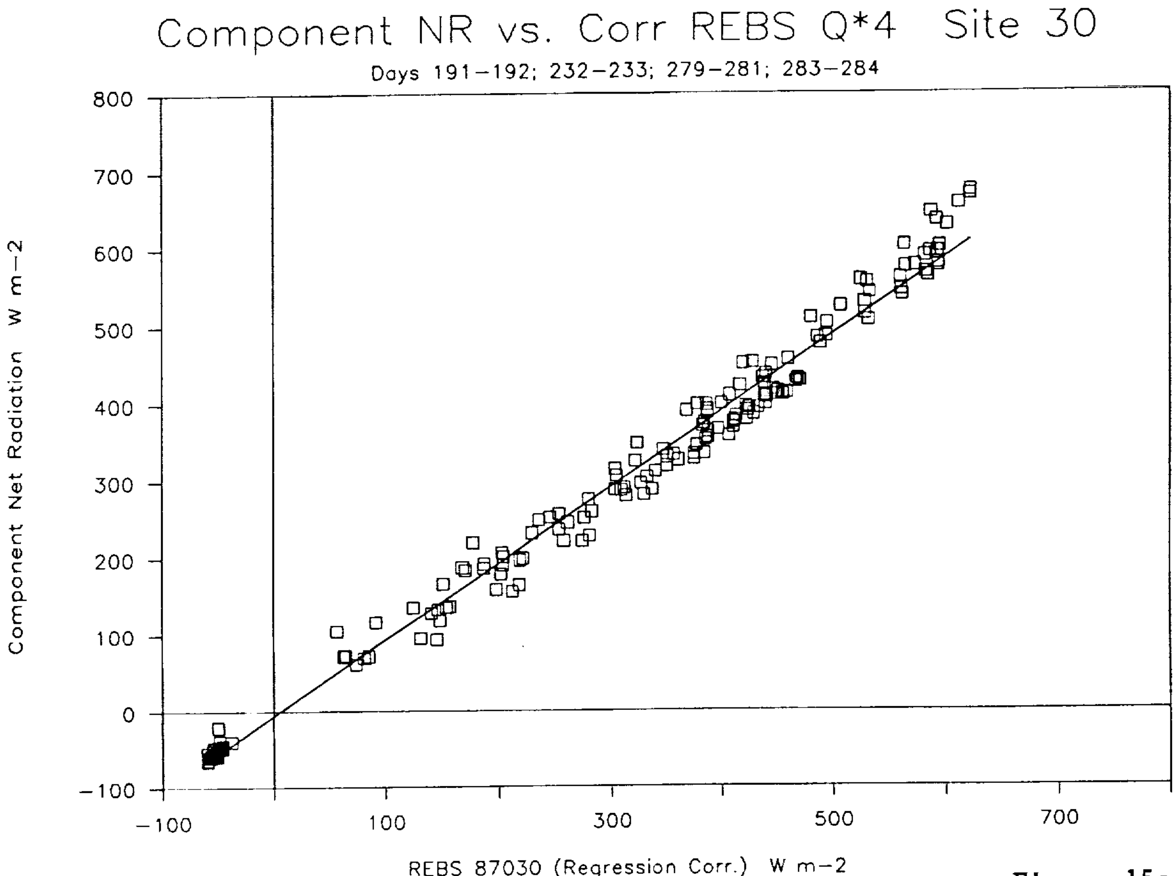


Figure 15a

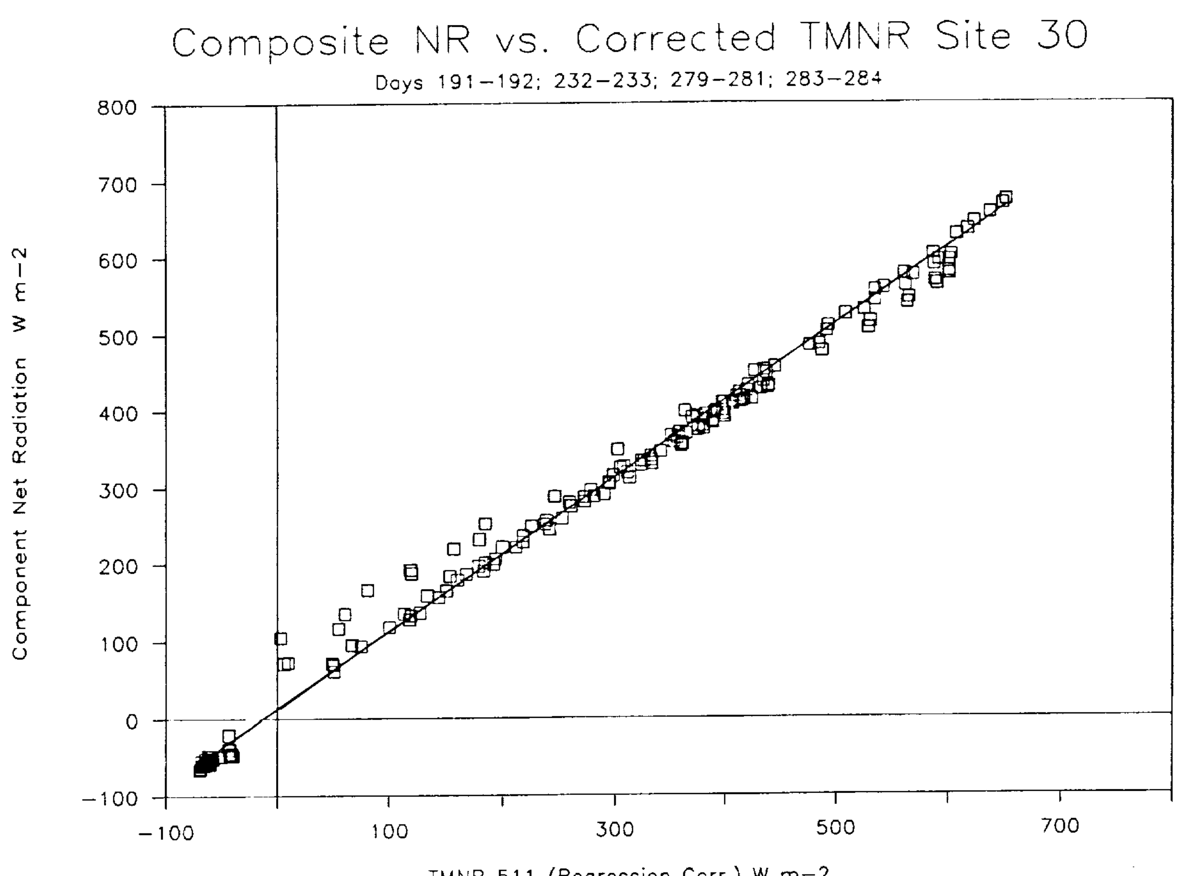


Figure 15b

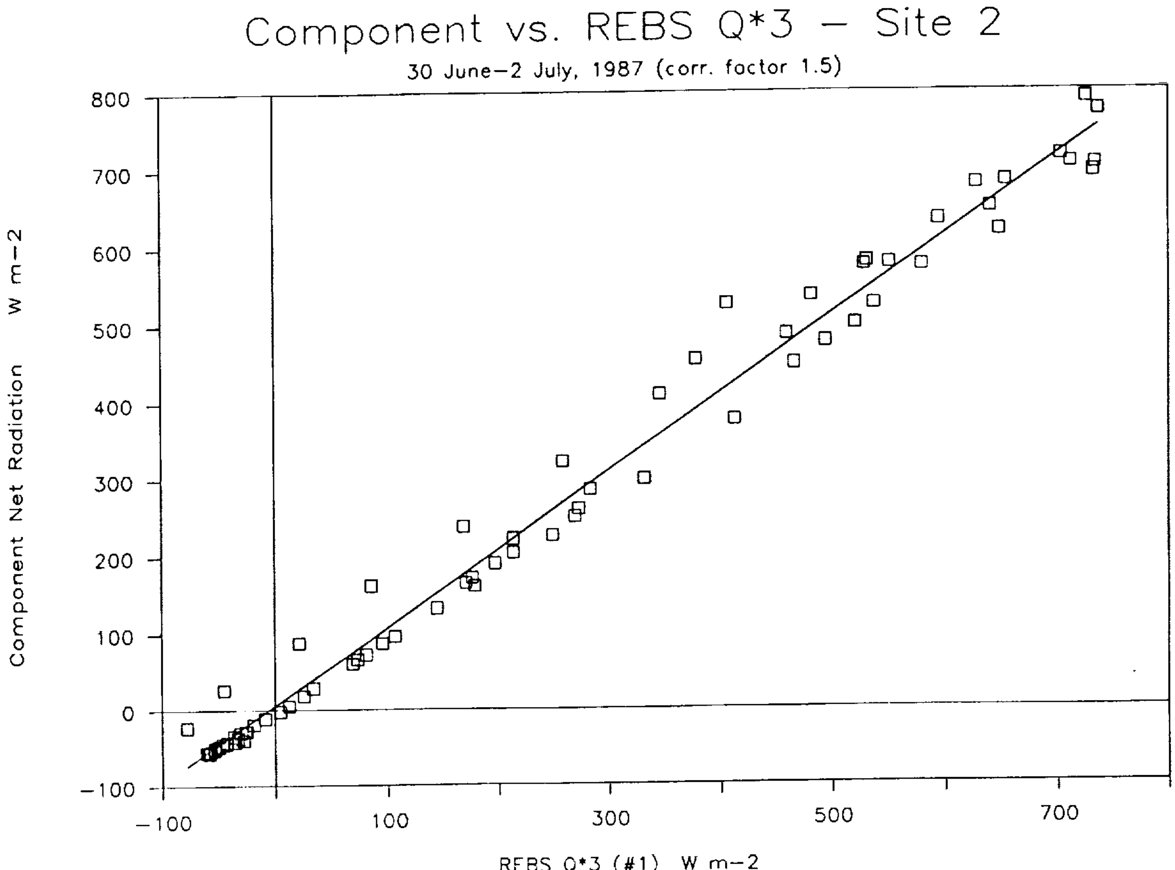


Figure 16a

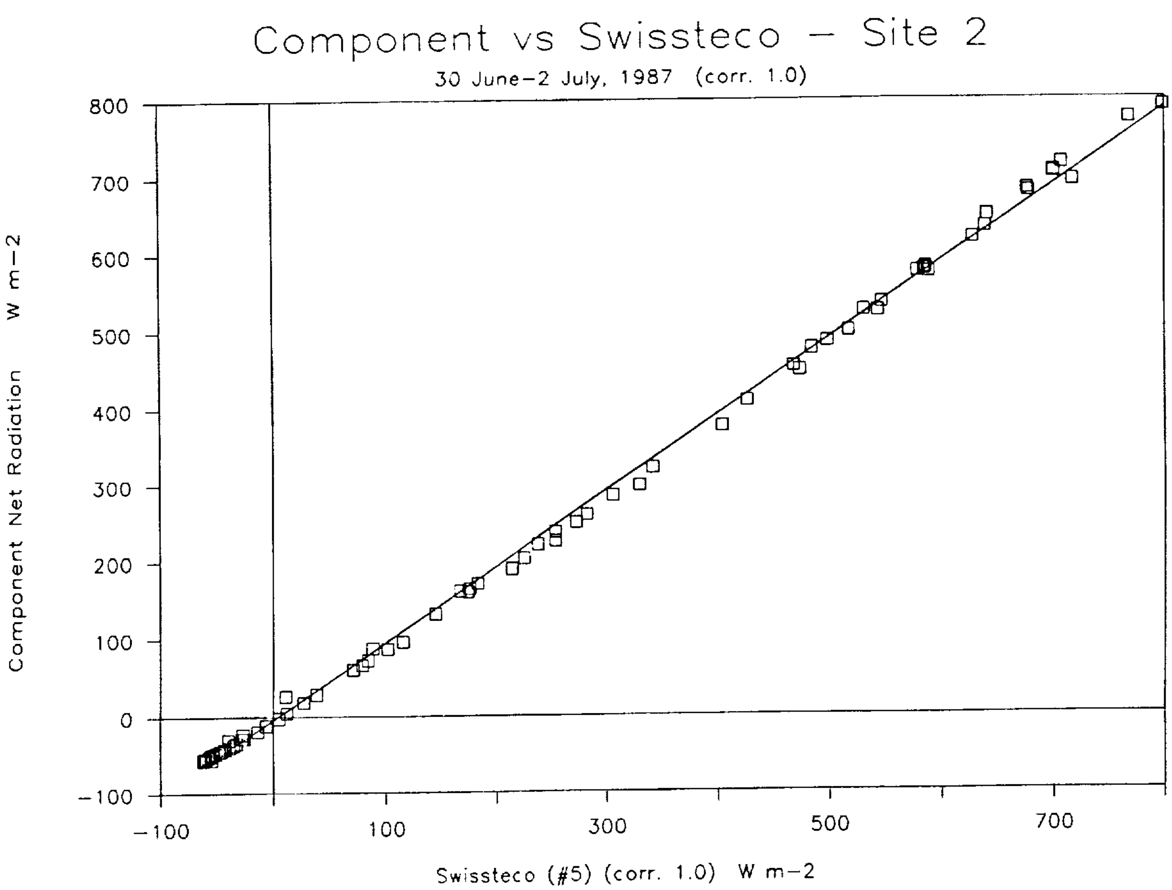
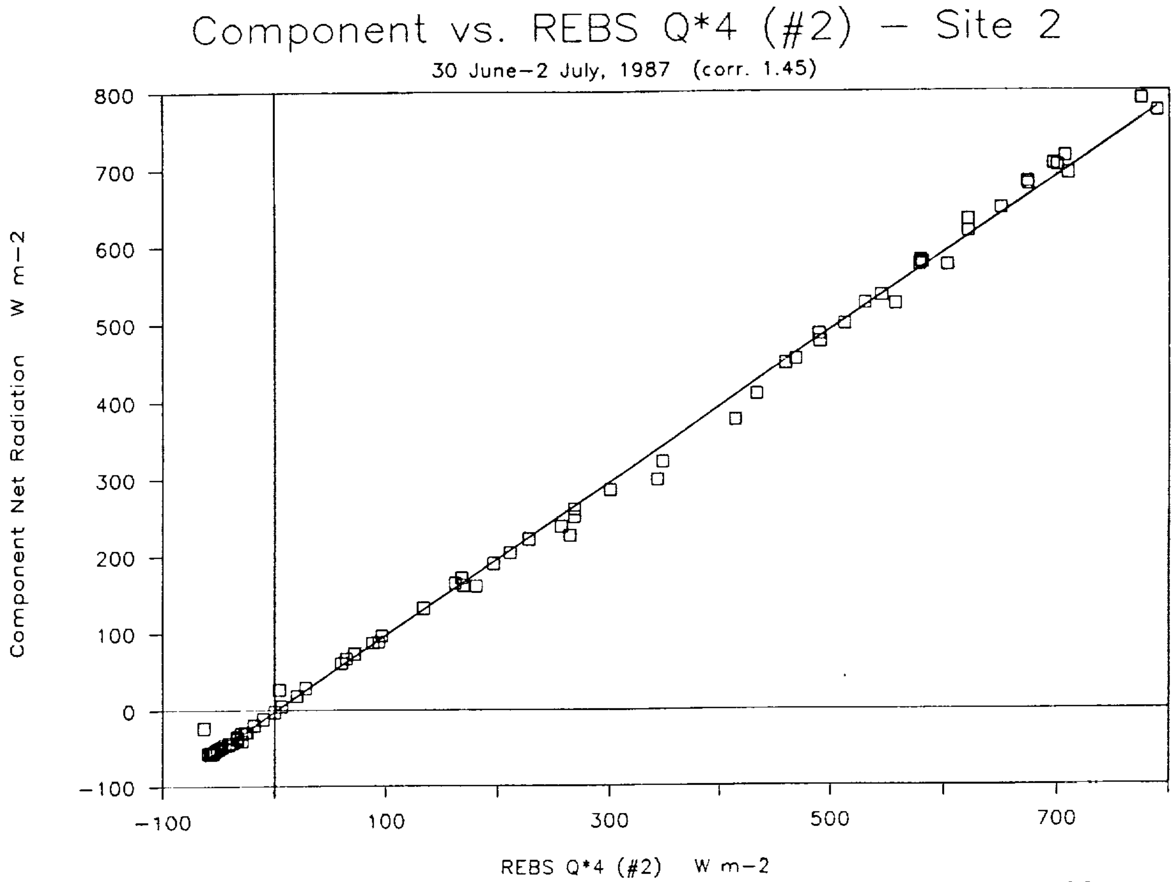


Figure 16b



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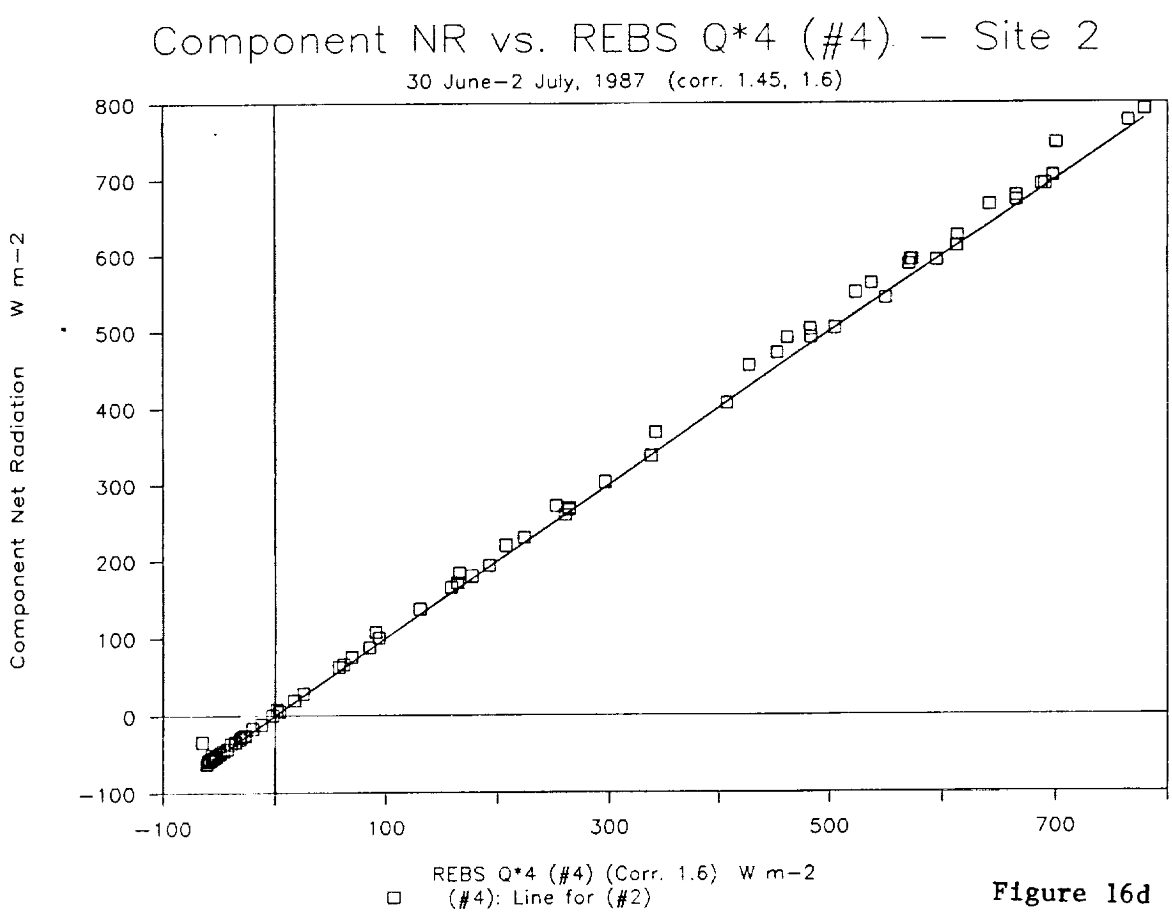

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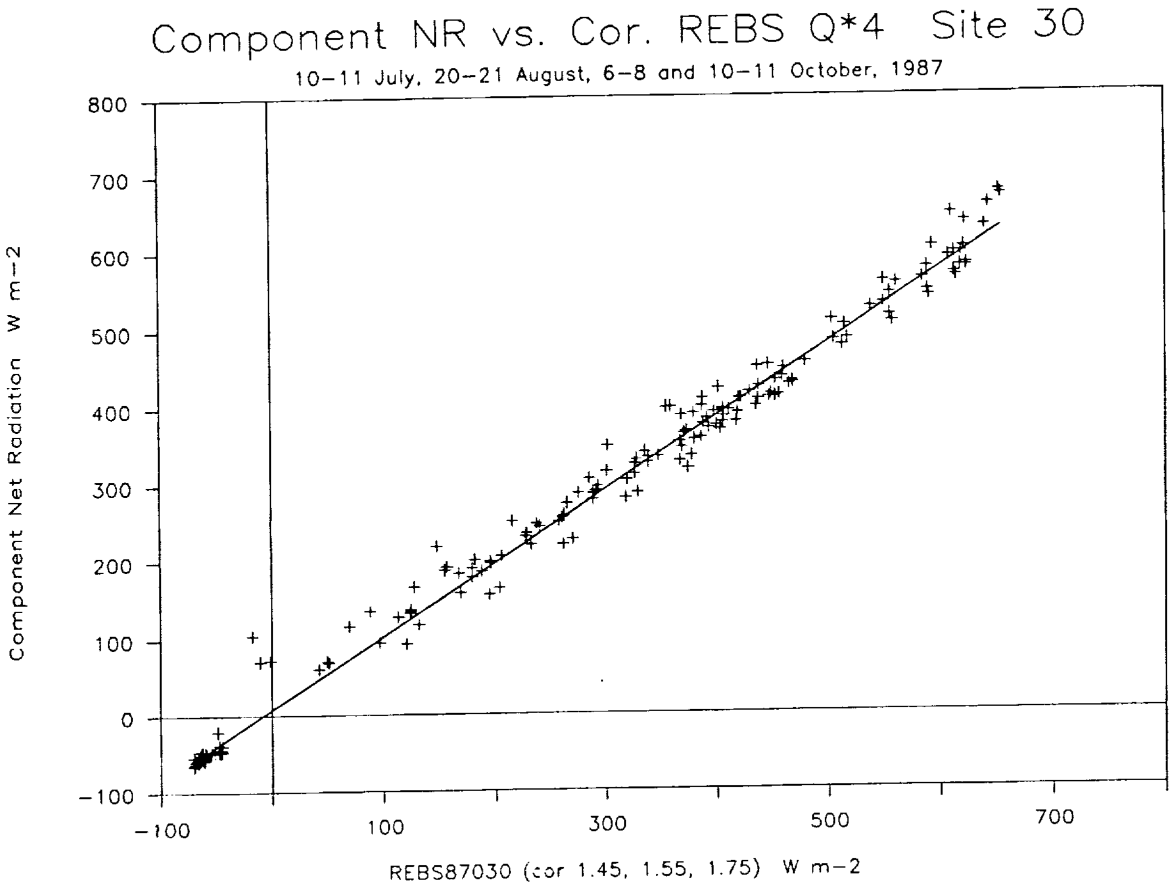
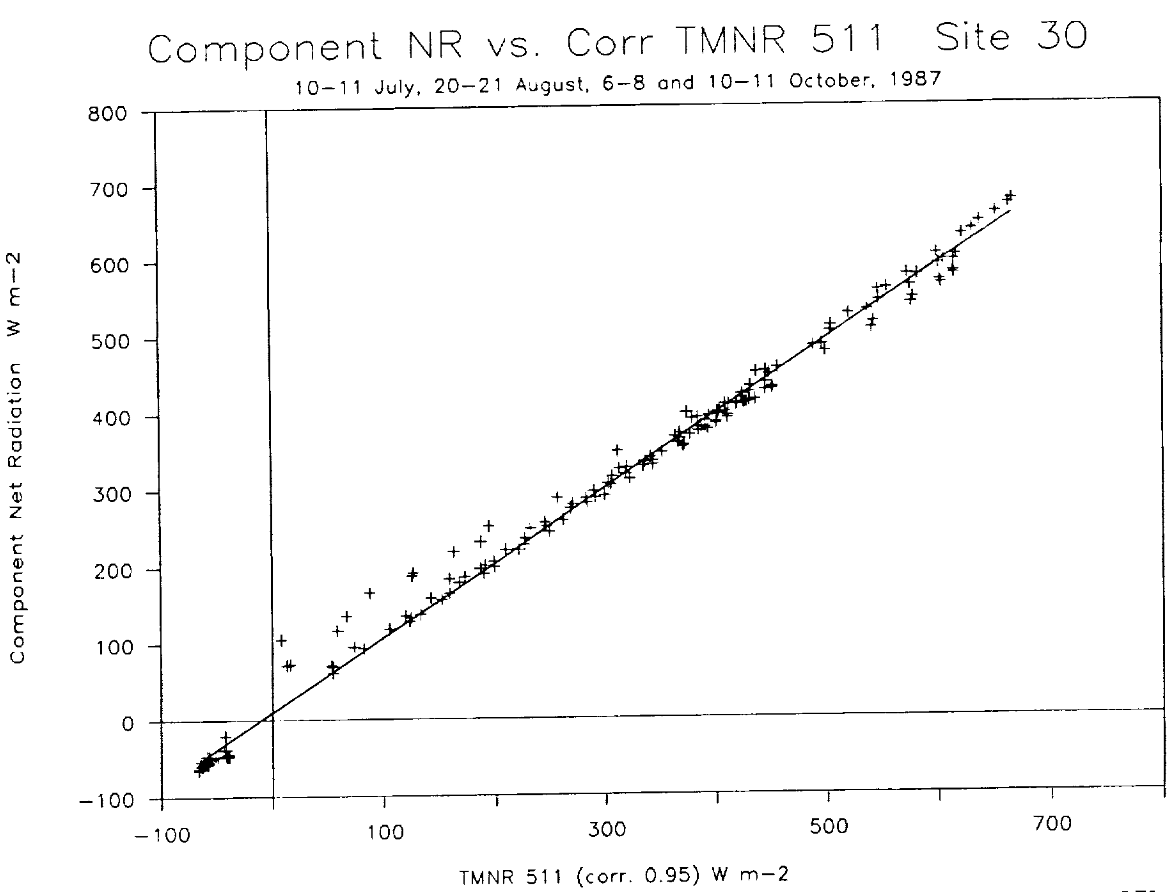


Figure 17a



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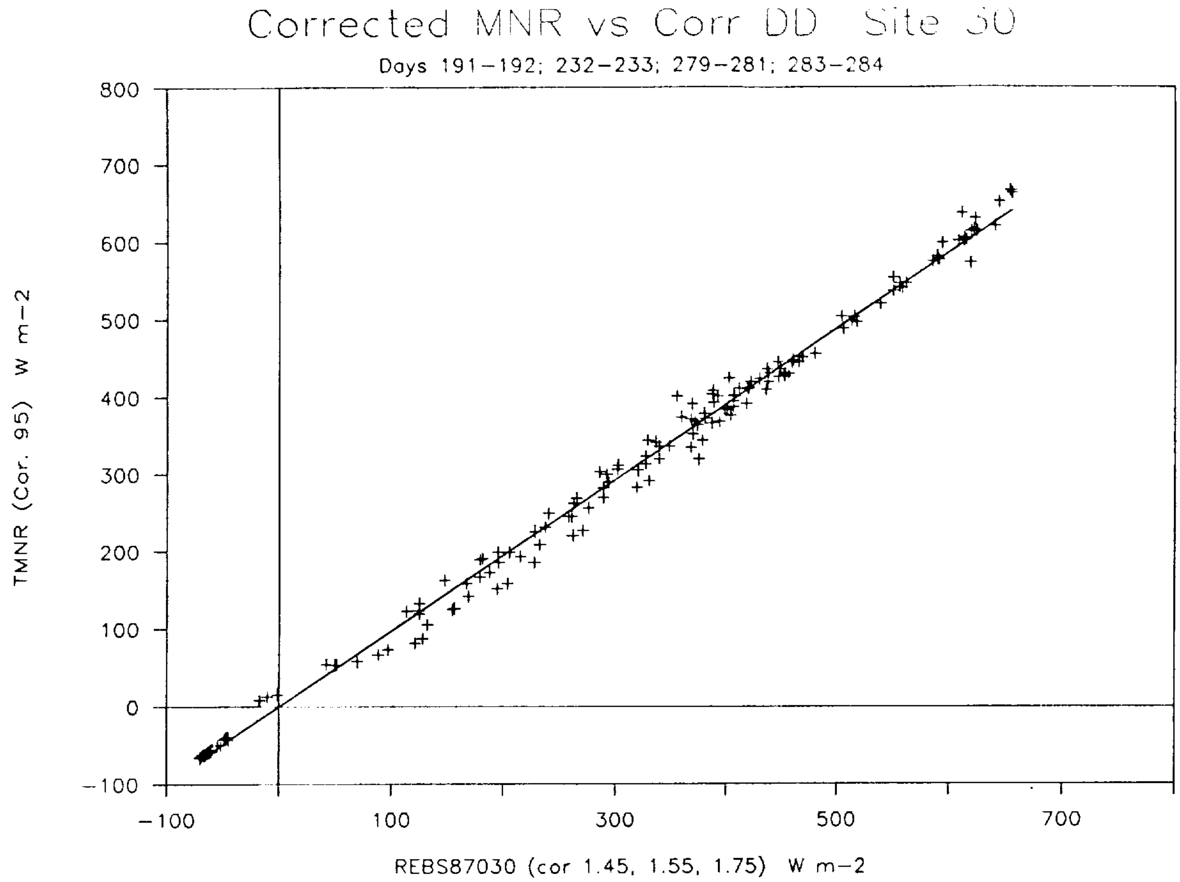

Figure 18a

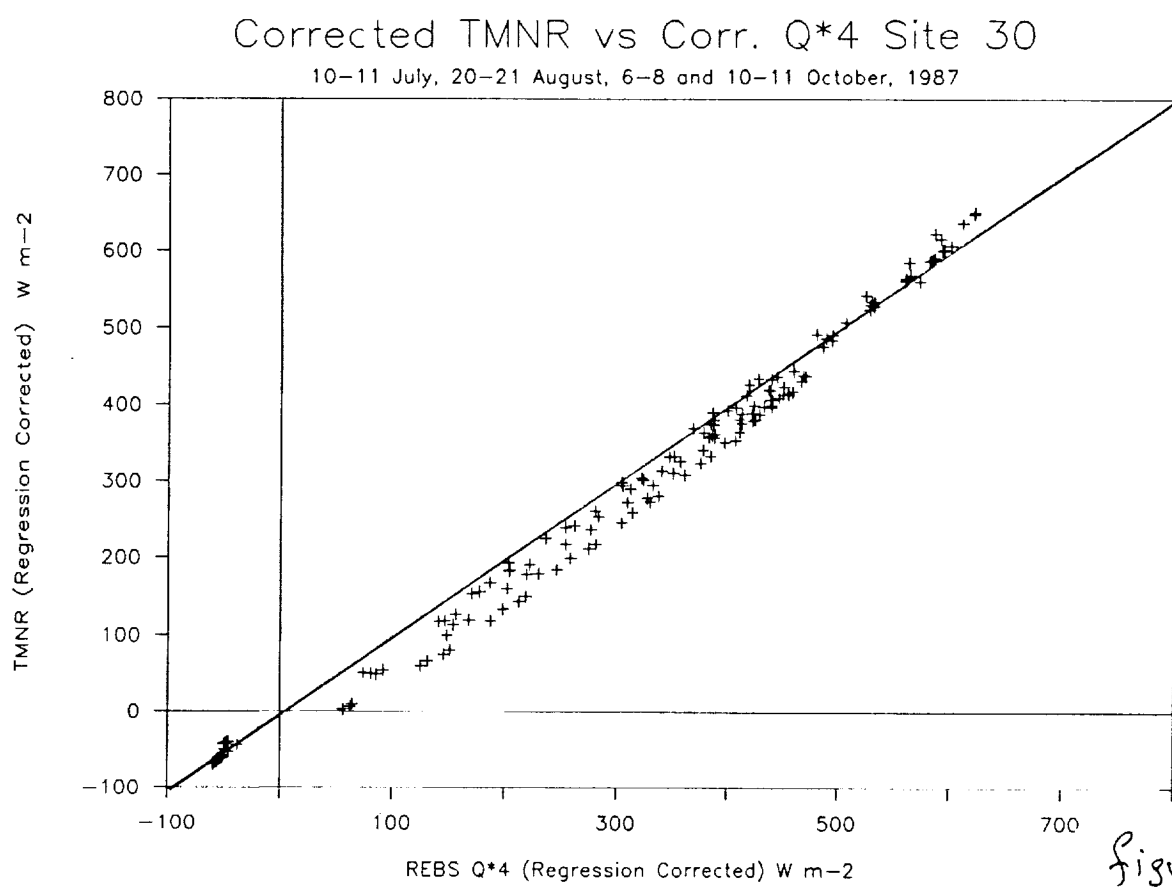

figure 18b